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Gamma Radiation Treatment of Waters from Lignite Mines

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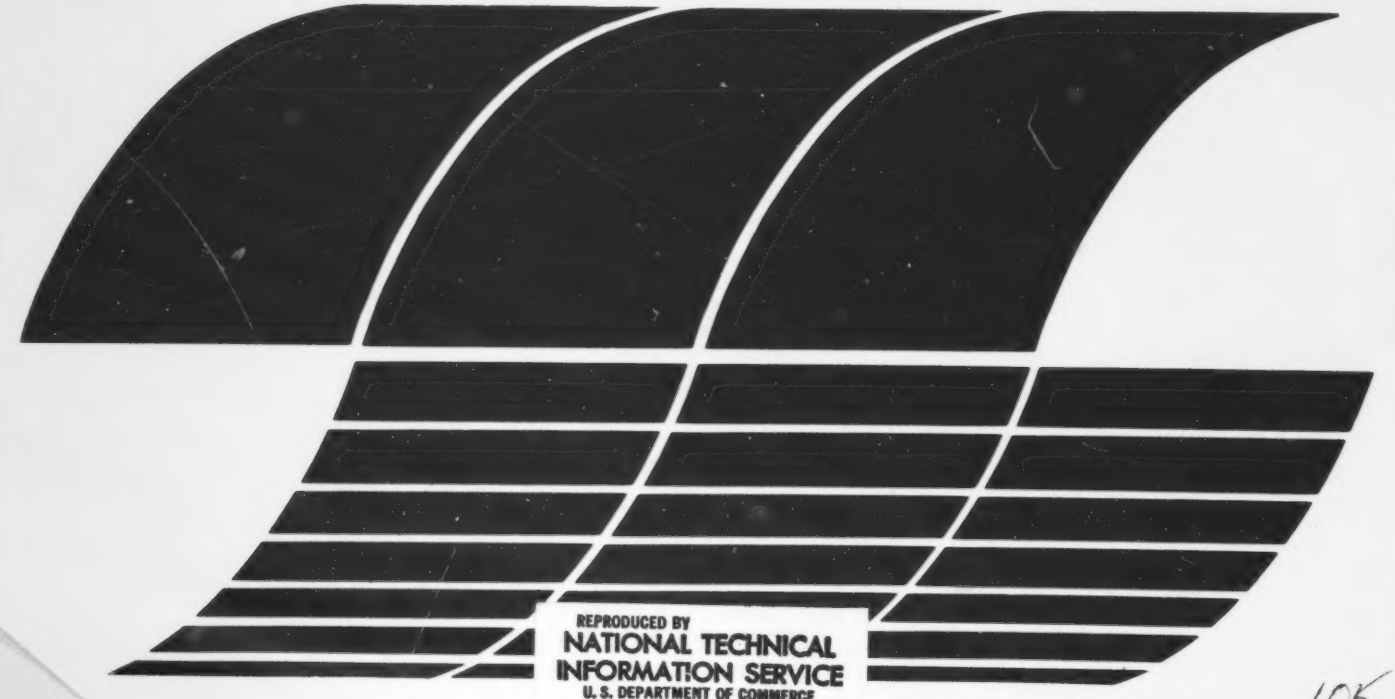

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Discussed in this report are results of laboratory investigations carried out with the application of gamma radiation for the purification of waters drained from surface lignite mines. These waters are polluted to a considerable extent with suspended matter of various sizes, a large quantity of which is colloidal particles, mainly clay, that create turbidity and colour. Moreover there is often a high oxygen demand occasionally a high content of iron. The remaining chemical physical parameters of the mine water do not diverge from the levels required for waters discharged to surface flows and reservoirs.

The investigations have shown a positive influence of Co-60 gamma radiation on the speed of suspended matter sedimentation, starting with an absorbed dose of 500 kRad. An optimal dose was found to be 1000 kRad. Above this dose the acceleration of velocity of settling particles was not proportional to the applied energy value.

The investigations found relationship between the absorbed dose and the reduction in turbidity, oxygen demand and iron content. Also change in electrokinetic potential, and other relationships illustrating the effects of water irradiation were determined.

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GAMMA RADIATION TREATMENT OF WATERS FROM LIGNITE MINES

by

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Grant No. 05-534-3

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

The effort reported here was conducted as part of the Environmental Protection Agency's Scientific Activities Overseas Program. The research was conducted by Poltegor, Central Research and Design Institute for Opencast Mining, Wroclaw, Poland.

In this report laboratory studies on the use of gamma radiation treatment to improve the removal of suspended solids and color from lignite mine drainage are discussed. Although gamma radiation was found to be effective for this use, the technique did not appear to be applicable to United States conditions. Results of this work will be of interest to investigators concerned with gamma radiation treatment of industrial waste.

For further information contact the Extraction Technology Branch, Industrial Environmental Research Laboratory-Cincinnati.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

SCIENTIFIC ACTIVITIES OVERSEAS

(Special Foreign Currency Program)

Scientific Activities Overseas, Developed and implemented under the Special Foreign Currency Program, are funded from excess foreign currencies accruing to the United States under various U.S. programs. All of the overseas activities are designed to assist in the implementation of the broad spectrum of EPA programs and to relate to the world-wide concern for environmental problems. These problems are not limited by national boundaries, nor is their impact altered by ideological and regional differences. The results of overseas activities contribute directly to the fund of environmental knowledge of the U.S., of the host countries and of the world community. Scientific activities carried out under the Program therefore offer unique opportunities for cooperation between the U.S. and the excess foreign currency countries. Further, the Program enables EPA to develop productive relationships between U.S. environmental scientist and their counterparts abroad, merging scientific capabilities and resources of various nations in concerted efforts toward U.S. objectives as well as their own.

Scientific Activities Overseas not only supplement and complement the domestic mission of EPA, but also serve to carry out the mandate of Section 102/2(E) of the National Environmental policy Act to "recognize the world-wide and long-range character of environmental problems, and where consistent with the foreign policy of the United States, lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind' s world environment".

This study of purification of water from open pit lignite mines has been funded from Public Law 480. Excess foreign currency money is available to the United States in local currency in a number of countries, including Poland, as a result of a trade for U.S. commodities. Poland has been known for its extensive mining interests, environmental concern, and its trained and experienced engineers and scientists in this important energy area.

ABSTRACT

Discussed in this report are results of laboratory investigations carried out with the application of gamma radiation for the purification of waters drained from surface lignite mines. These waters are polluted to a considerable extent with suspended matter of various sizes, a large quantity of which is colloidal particles, mainly clay, that create turbidity and colour. Moreover there is ofter a high oxygen demand ocassionally a high content of iron. The remaining chemical physcial parameters of the mine water do not diverage from the levels required for waters discharged to surface flows and reservoirs.

The current method of purification of mine waters is limited to the reduction of excessive quantities of suspension and turbidity by large field sedimentation basins. For some waters containing high quantities of colloidal suspensions of high zeta potential and also during periods of adverse weather conditions the current technology was not producing satisfactory results. This finding established the weed for a search for new more effective methods of water purification.

One of such methods evaluated was the use of gamma radiation. Investigations were carried out under laboratory conditions in a special radiation chamber. Samples of water characterized with different contents of suspensions and turbidity were subjected to the action of gamma radiation, employing doses within the limits of 100-2000 kRad with slow dosing of 200 kRad/hour and fast dosing of 600 kRad/hour rates.

The investigations have shown a positive influence of Co-60 gamma radiation on the speed of suspended matter sedimentation, starting with an absorbed dose of 500 kRad. As optimal dose was found to be 1000 kRad. Above this dose the acceleration of velocity of settling particles was not proportional to the applied energy value.

The investigations found relationship between the absorbed dose and the reduction in turbidity, oxygen demand and iron content. Also change in electrokinetic potential, and other relationships illustrating the effects of water irradiation were determined.

This report was submitted in fulfillment of Contract No. 05-534-3 by the Central Research and Design Institute for Opencast Mining, Poltegor, Poland by the subcontractor POLON Poznań under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers a period from September 1, 1974 to August 31, 1976, and work was completed as of 31 March 1978.

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Dr. H.F. Turała, General Director of Poltegor and dr. Jacek Libicki, coordinated the research with the U.S. Environmental Protection Agency. The research work was directed by Henryk Janiak, M.Sc.

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SECTION 1

SUMMARY AND CONCLUSIONS

Seven series of tests were conducted to determine the effect of Co-60 gamma radiation treatment on waters discharged from Polish surface lignite mines. Waters from three Polish mines, Turów, Konin and Adamów were utilized. The major emphasis of the research was on the removal of suspended matter from the water by increasing the sedimentation rates. In addition changes in pH, COD and zeta potential were monitored. The effect of radiation intensity and dose were also determined.

Conclusions drawn from this research were:

1) In all waters investigated a beneficial effect of radiation by Co-60 gamma on the rate of colloidal suspension sedimentation was observed.

2) An explicit influence of radiation on the rate of sedimentation occurs beginning with an absorbed dose of 500 kRad.

3) The rate of sedimentation of irradiated waters increases with an increase of the absorbed dose. The optimum in the relationship of time of irradiation to effect of purification occurs at an absorbed dose of 1000 kRad.

4) The greatest effect in increased clarification occurs with waters having an appreciable natural COD. The suspended solids contained in these waters precipitate much faster after irradiation than is the case of control samples.

5) No decisive beneficial influence on the speed of water purification after irradiation was found due to the change in the waters' pH value.

6) The changes in the pH and the COD of the treated waters and the simultaneously small changes in the zeta potential suggest that by a chemical and not a physical process the radiation influences the colloidal suspension removal from waters of lignite mines.

SECTION 2

REVIEW OF WORLD LITERATURE

SOURCES

Sources of radiation became available for industrial use during the 1950's. From that time on an interest in the use of radiation for the removal of the pollutants has occurred. The first studies concerned disinfection and sterilization of waste waters, but it soon became obvious that radiation application had far greater possibilities. The main effects were with radiation treatment to remove oxygen demand, with modification of organic particles, with changes in colloidal systems and with a destruction of micro-organisms and parasites[1]. These processes lead to a reduction in the chemical and biological oxygen demand, and to an improvement in the sedimentation of suspended matter, and to the dewatering of sediment.

In radiation practice two types of radiation are considered: (1) the highly active gamma and the beta radiation for which the isotopes Co-60 and the Cs-137 are employed as sources, and (2) the low activity, low yield, and short half-life emitters, which have not proven effective on an industrial scale. Ballantine[2] has discussed the prospects of various radiation sources in their purification processes application.

The Co-60 isotope is produced in reactors from a stable Co-59 during a neutron activation. In contrast to cobalt, the Cs-137 is obtained from processing spent reactor fuel, which contains a mixture of many

isotopes. Co-60 radiation used for practical purposes involves gamma rays of energy 1.17 and 1.33 MeV (megaelectrovolts).
Cesium emits gamma radiation of 0.66 MeV. Therefore, the energy of Co-60 required for a one kW power source amounts of 67 KCi, whereas the energy of cesium for this same power would be 300 KCi. The sources of the Co-60 are only about 10 % self-absorptive, whereas the Cs-137 is as much as 50 % self-absorptive. For this reason the useable energy from cobalt sources is less limiting in terms of source geometry, while for the cessium sources the useable activity is highly dependent on the geometry of the capsule. For similar reasons cobalt uses a few times less space than cessium for sources of the same activity. Cesium-137 has one great advantage, its long half-life of up to 30.2 years, whereas Co-60 is 5.26 years, therefore in order to maintain the intensity of the sources one has to supplement annually the cobalt activity by 12.5 %, and cesium only by about 2.3 %.

Attention has also been given to Cs-134, which is also found in spent fuel from power reactors. If the two cessium isotopes are not separated, then a source of 3-times greater specific activity than Cs-137 can be obtained. The cesium-134 has a half-life equal to 2.1 years and for the attainment of 1 kW rating 150 KCi of the isotope is needed. A natural mixture of Cs-137 + 134 possesses a power density equal to 11.7 W/KCi, as opposed to 3.35 for pure Cs-137 and 15 W/KCi for the Co-60. A negative characteristic of this mixture is the relatively short half-life of the Cs-134, which makes necessary frequent replenishment.

An accelerator of electrons can be employed in place of an isotope gamma radiation source. An accelerator produces a stream of high energy electrons, possessing the ability to initiate physiochemical changes similar to the gamma radiation. The energy of emitted electrons depends on the rating of the given accelerator, but the suitability of high energy electrons is limited to about 10 MeV[3]. The electrons with higher energy may induce radioactivity in the irradiated material.

Although Ballantine[2] proposes a higher limit of 15 MeV, such high energy radiation would have only limited use, i.e., where no elements with a low threshold of activation are present.

For practical considerations accelerator producing electrons energies 0.5-3.0 MeV are used. The power rating of accelerators producing such energies ranges from few to 50 kilowatts. The main disadvantage of the electron radiation is its small depth penetration, which for water is about 0.5 cm per 1 MeV, while the useful penetration of gamma radiation in water is 1-2 m depth.

Advantage of the accelerators is that they are electrical installations, and therefore their production is not limited, whereas the sources of gamma radiation are limited by the development of the nuclear power industry. Moreover, in comparison with the gamma emitters the capital cost for the same acquired energy from the accelerators is 6-10 times less, and the operating costs are 2 times lower[2].

It is significant that the effects of the irradiation are independent of the kind of radiation but only on the absorbed dose quantity by the irradiated water[4]. Therefore despite the limited range of the fast electrons, there has been increasing interest in accelerators for the removal of pollutants.

Consideration has been made of the possibilities of using the mixtures of fission products, the spent fuel elements from the nuclear power plants and even the entire nuclear reactors as sources ionizing radiation[5, 6, 7]. However, technical problems are such that their use in the near future for industrial scale application is small.

Mechanism of Radiative Sedimentation of Colloids

The effect of ionizing radiation on the stability of colloids was studied even before the development of the radiation chemistry as part of a nuclear industry. Before World War II a group of Crowther's

coworkers had indicated that the charges of colloidal particles change under the influence of radiation. These efforts were concerned with small doses not exceeding 10 Krad. However, the effect was most apparent for a dose of 1 Krad and smaller. In actual use of radiation to destabilize colloidal suspension doses as high as a few Mrad are employed. With high doses the changes in electrostatic charge of the colloidal particles are less important, because the major impact is the effect on the radiochemical prosesses, either on the direct effect of radiation on the colloidal particle, or on the secondary reactions taking place between the suspended fractions and the products of aqueous radiolysis. Both processes lead to the degradation of high molecular colloids, and to their complete oxidation. Where a colloidal particle is suspended in water ionization, due to electron or gamma interaction causes a process of water radiolysis. This leads to the formation of short - lived particles and H and OH radicals, which are discussed later (2,4).

In the presence of oxygen in water additional radicals and 0_3 are formed, both species being highly oxidizing agents. For effective removal of suspended solids the process reacts best in the presence of high concentrations of dissolved oxygen (8). A degradation of the colloidal particle results and a precipitation occurs, or in extreme cases a complete oxidation of organic matter into carbon dioxidide and water can take place.

As far as an inorganic suspension such as the $Si0_2$ is concerned, an increase in sedimentation even by a relatively low doses of 1 Krad can be obtained[9].

Installations Utilizing Gamma Radiation

The equipment for fluid irradiation and for the treatment of suspended matter can be divided into two types: static and dynamic. Static equipment is primarily used for laboratory investigations, since continuous flow operation is required in industrial use. Thus, the discussion

here will be primarily on the dynamic type.

Two processes for the removal and disintegration of suspended matter have been described. Both processes have been studied on a large scale. One process reported by a group of scientists from West Germany, Lessel, Motsch, and Menning[10] concerned the modification of sewage sludge for agricultural use. The scheme of this process is shown in Figure 1. The plant, which was constructed in 1972/73, was designed to treat 30 m^3 of sewage a day with an absorption dose of the 300 KCi. The design capacity provided for an increase in 150 m^3 without change in dose, or additional equipment. The installation consisted of two underground shafts, one contained the irradiation source in a centrally built-in tube, in which the sewage was circulated, and a second containing pumps, pipelines and valves. The above ground portion contained storage silos, a lift, control equipment and a small laboratory. The lift was required to raise the heavy cover of the radiation shaft. The radiation source was Co-60, with an activity of 100 KCi. Sewage was pumped to the storage silos before treatment. The sewage was circulated on both sides of the radiation source and recirculated until it had absorbed the required dose. Batch capacity of the irradiated system was 5.6 m^3. After radiation treatment the sewage was pumped to a drying area. The system was very simple. The radiation shaft did not contain moving parts. All pumps, equipment, valves and indicators were placed either in the accessible pumping shaft or in the above ground building, thus maintenance and control was always possible without exposure to the dangers of radiation.

Disadvantages of this system was the cyclic operation and employment of pumps. It would appear that in the case of sewage, in which the suspended matter is not intended for further use, the installations could work on a continuous basis. The irradiated sewage could be directed to a sedimentation basin. A system of valves and pumps would ensure the desired dose to the sewage.

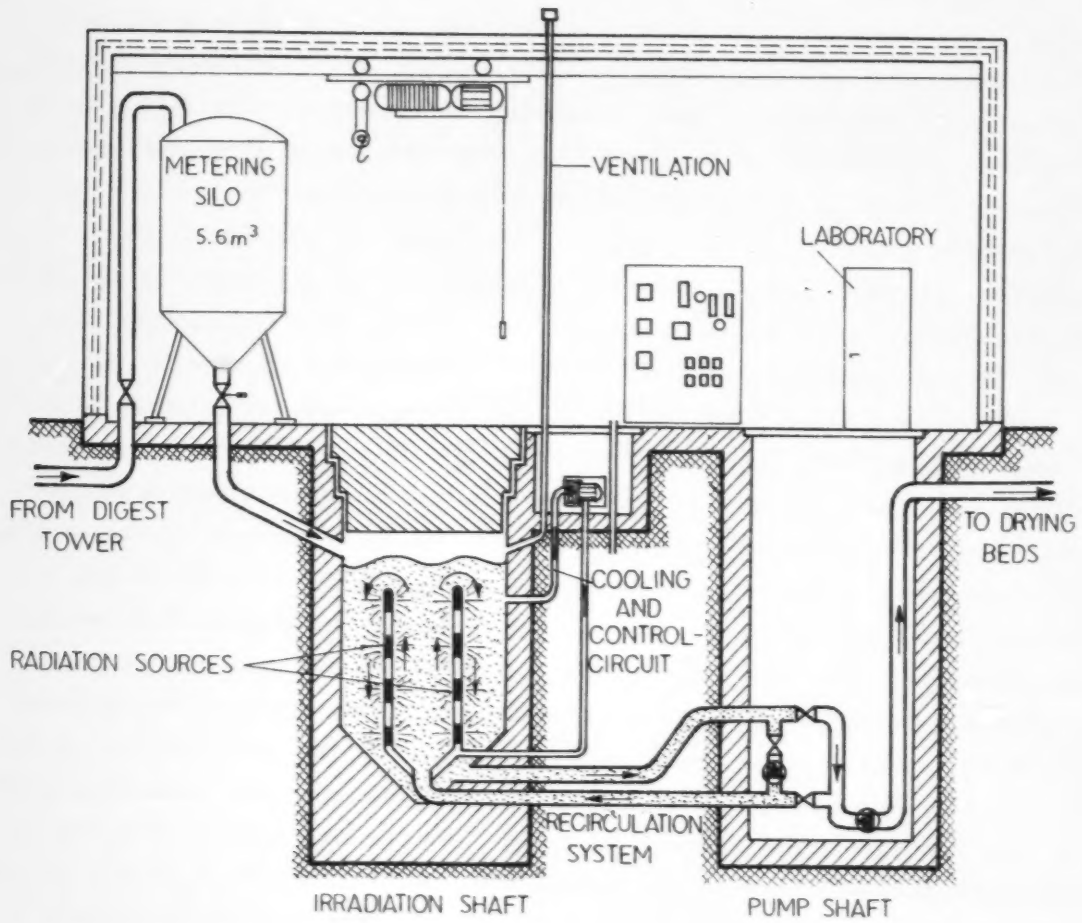


Fig. 1. Scheme of Plant for Sewage Sludge Irradiation at Geiselbullach

Reference 10

The second operating installation was an experimental treatment plant constructed in 1973 in the United States. The results were presented by Hay[11] at a symposium in Munich in 1975. The results of an 18-month study seemed to be sensational. The process is based on a phenomenon, which was first described by Mr. Ketchen and Case[12] in which activation of an in situ carbon filter occurs in the presence of oxygen with the help of a strong source of ionizing radiation. The filters of activated carbon have been used for some time in conventional water treatment. Their major drawback has been the rapid clogging of the carbon by absorbed material, and the periodical removal and thermal regeneration of carbon. There is a loss of carbon due to regeneration and hydraulic transport. These disadvantages result in carbon filtration being rather expensive.

In the process described by Hay, the charcoal did not undergo changes and showed no losses for the 18 months of the investigations. The suspended matter adsorbed on the carbon surface was completely oxidized by the gamma radiation in the presence of oxygen dissolved in the water. Products of oxidation were water and carbon dioxide. A diagram of the installation is shown in Figure 2.

The installation had a rating of 5000 gallons per day, with a sewage containing 100 ppm of suspended matter, or 500 gallons per day with 500 ppm suspended matter. The flow through the system was by gravity. The dose of 1 Mrad was generated by a Co-60 source. The activity of the source was not presented. Test was initiated with poultry waste and, later on municipal and industrial waste. The results of this treatment was that color was reduced in 90-99 %, the chemical oxygen demand (C.O.D.) 90 %, more than 99 % of coliform type bacteria were killed, and 95 % and more of other bacteria were destroyed.

Oxygen was supplied to the waste before radiation treatment in a special container fitted with stirrers. A concentration of 11.5 mg/l was sufficient to carry out the process.

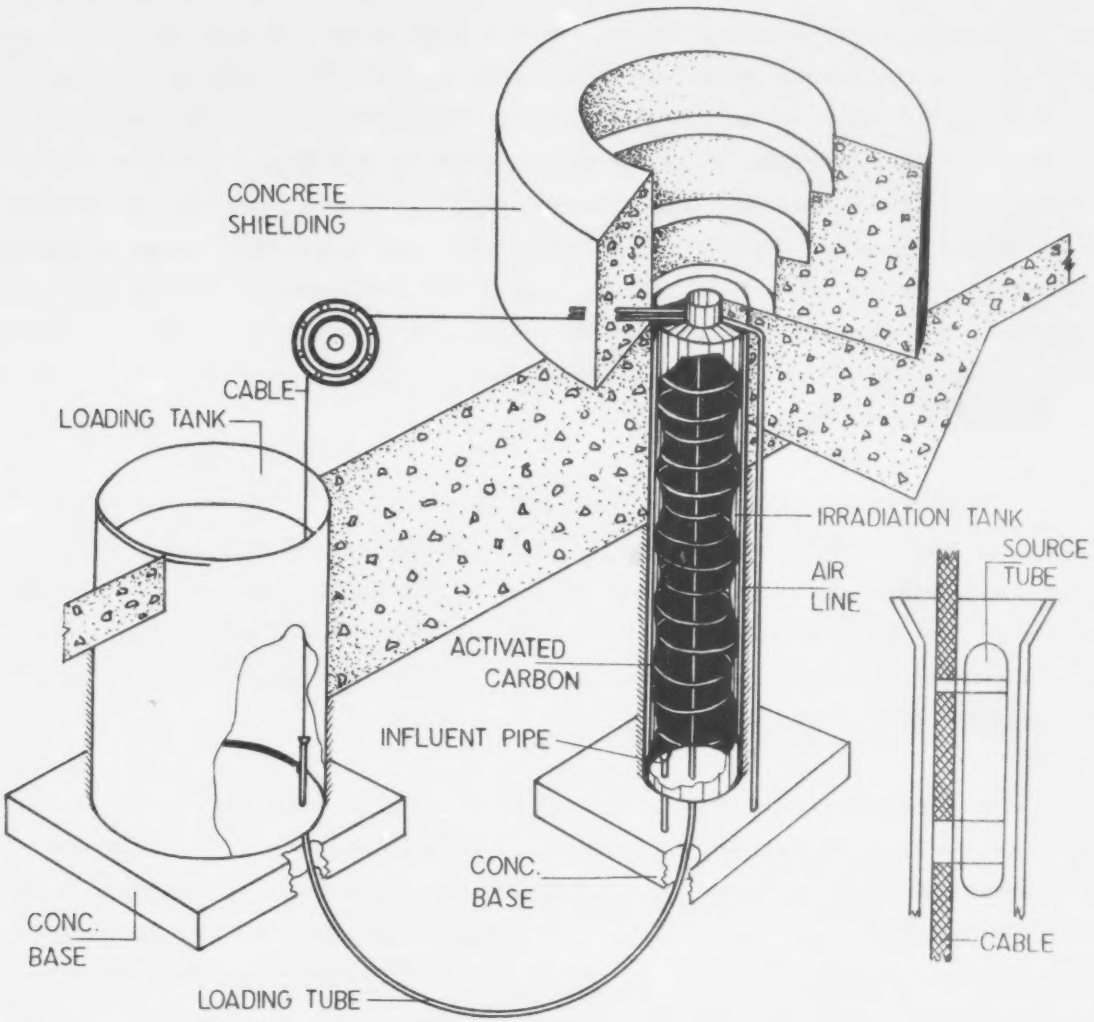


Fig. 2. Gamma Radiation Process with Carbon

Reference 11

Due to the installation of the radiation source on the filter a very good efficiency of the dose utilization was achieved. The irradiation does not effect the water (which is 99 % of the flow) but only the adsorbed matter on the filter.

Installations Utilizing the Accelerators of Electrons

As already mentioned the employment of electron accelerators is limited by a small range of the electron in water. Nonetheless, it appears from the analysis of costs and from technical facilities, that the use of accelerators in place of gamma radiation sources seems to be justified and a number of tests have been made utilizing these systems to treat sewage. Published reports indicate that all of the work has taken place on a laboratory scale, although attempts are being made to go to a larger scale. In 1974 the Massachusetts Institute of Technology[13] began work on an accelerator installation with a capacity of 100.000 gallons per day, for the removal of pollutions from waters.

Another planned arrangement on an industrial scale is a treatment plant intended to purify wastes at a factory for antibiotics in the Soviet Union[14]. The planned capacity of this treatment plant is 15.000 m^3 per day. The irradiation is to serve as an initial treatment.

The Soviet Union installation is to consist of two accelerators of the transformer type having a beam of electron radiation with an energy of 0.7 MeV and the power rating of 40 K watts. The flow will pass gravitationally through an underground radiation chamber, which is lined with porous panels. Under the panels will be air blowers. The air will penetrate through the porous panels and mix and aerate the flowing fluid, and prevent sedimentation in the irradiation chamber. Dosage will be in the 2 Mrad range. The above installation was to be completed by the end of 1975. So far there is no information regarding the results of these studies.

Costs

In the Ballantine work[2] an evaluation of costs connected with a radiatior treatment was made. It appears that the most expensive installations would be those employing Co-60 as source of radiation, while the cheapest is the electron accelerator. Of course the costs will depend not only on the employed source of radiation, but also on the kind of suspension. Ballantine's earlier work[5] reported that the costs increased proportionally as the amount of suspended matter contained in sewages increased and on the wastes amenability to radiation disintegration. He considers that the cost limit for radiative purification is 1-2 dollars per 1,000 gallons. This value is probably correct, because the price of a conventional treatment of sewage, with the same efficiency of purification, is similar.

The cost of sewage purification by radiation oxidation on activated carbon, as described by Hay[11], amounts to 28-30 cents for 1000 gallons with the content of organic substance 200-250 ppm. This cost has been calculated for a 20-year depreciation investment period. A similar period of depreciation was taken as the basis of cost calculations in the employment of the electron accelerators[14]. In the calculations of the authors the cost of conventional treatment of 2 m^3 amounts to 0,56 Russian roubles. With a radiation treatment this cost would be lowered to 0,45 roubles. In the work of German researchers[10], the cost of conventional treatment was about 10 % lower than the radiation treatment (4 D.M. as against 4,42 D.M. for m^3).

Summary

The radiation removal of pollutants from water, is slowly but systematically gaining in development. It is a part of the research programs of most progressive countries. A system competitive to conventional treatment is the major goal. The advantages of radiation treatment is the simplification of the process, and the increase in purification efficiency. Costs of production as reported here are comparable to conventional methods.

SECTION 3

THE THEORETICAL ASSUMPTIONS

Influence of Radiation Ionizing the Matter

Ionizing radiation, or simply radiation is the name given to short-wave electromagnetic radiation the x - Rays and gamma, high energy charged particles - electrons, protons, deuterons, alpha particles, recoil nuclei and also fast neutrons. If the energy radiation exceeds the energy necessary for the ionization of atmos or of particles of some substance, then in passing through the substance ions are generated.

The activation energy for most substances is usually between 5 and 25 eV[16]. This energy brings the medium into a chemically active state, which can be compared to the rising of temperature in a system of slow reacting substances. For example a beam of x - rays with an intensity of about 50 rad/sec and maximum energy quantum 1 McV, is equivalent to a short duration temperature jump by 10^8 ^oK.
The formation of ions under these conditions do not occur at a regular rate as would be the case with thermal activation, but occurs in independent pulses, at 10^{-15} sec, or less during which 100 ions are formed.

In radiation chemistry two types of activation are distinquished, electronic excitation and ionization; in electronic excitation either the direct dissociation of particles into free radicals or the transition of energy of electronic excitation into the energy of oscillatory movement of atoms forming the particles takes place. Such an activated particle

can be compared with a molecule with a raised temperature. Chemical reactions of such particle can proceed either in interaction with other particles, or the excited particle can split itself into constituents, i.e., smaller stable fragments, or free radicals.

During the ionization of particles a "knocking-off" of an electron from the shell of a particle (or atom) takes place. Since the "knocking--off" of an electron from an external orbit requires the minimum outlay in energy, (i.e., from the so called optical orbit or valency orbit), the ionization occurs in the majority of cases in the "knocking off" of the electron precisely from this orbit. Ions can recombine with free electron leaving again an excited molecule capable of frequency to form radicals.

Radiation Processes Occurring in Water

Activation of transmitted radiation initiates numerous processes, leading to a dissipation of energy and to chemical transformations. These processes occur at rates determined by the nature of the particle, its energy and the state of the system under study e.g. temperature, pressure, etc.

The chemical reactions that occurred are varied and including a synthesis and a decomposition, polymerization and depolymerization, oxidation and reduction, hydrogenization and isomerization and any possible combinations of these.

In some cases little chemical transformation is observed. This is due to the specific characteristic of the system, which allows its energy to be dissipated by internal resonance processes rather than end in rupture. In such case the effectiveness of the radiation energy transformation into a chemical energy is small. Or the system may have little ability to change, because of its simplicity and or the stability of the original material.

A case of this type is the absence of chemical changes in pure water under the influence of radiation. The situation changes radically when water contains small quantity of pollutants, especially of organic nature. A radiolysis takes place in such water with an evolution of a number of ions and radicals, subject to numerous reactions, which are not well defined.

A thorough analysis of water radiolysis process goes beyond the scope of this report, therefore this report will only consider those areas necessary to eludicate that part of radiolysis which plays a rcle in the pollutant removal from water. Radiation penetrating through water activates the particles, which can be written as follows:

$$H_2O \rightarrow (H_2O)^x$$

These exicted particles react with the neighboring nonactivated water particles and form hydrogen and hydrogen peroxide:

$$(H_2O)^x + H_2O \rightarrow H_2 + H_2O_2$$

Excited particles are generated also when the ionization of water occurs, i.e., when the radiation knocks off electron from the outer electron shell:

$$H_2O \rightarrow H_2O^+ + e^-$$

In this instance the "knocked off" electron possesses sufficient energy, to activate a few more particles of water where apart from the excitation it can also induce a decomposition of the water particle:

$$e^- (5{,}6\ eV) + H_2O \rightarrow H^- + OH^\cdot$$

$$e^- (7.5\ eV) + H_2O \rightarrow O^- + 2\ H^\cdot$$

Ignoring intermediate reactions the final result is:

$$H_2O \rightarrow H^{\bullet}, OH^{\bullet} \quad (H_2, H_2O_2)$$

The $H^{\bullet}$ and $OH^{\bullet}$ have the character of radicals and in the presence of organic substances and oxygen are the initiators of a chain reaction according to the following:

$RH + OH^{\bullet} \rightarrow R^{\bullet} + H_2O$ the start of chain reaction

$R + O_2 \rightarrow RO_2^{\bullet}$

$RC_2^{\bullet} + RH \rightarrow ROOH + R^{\bullet}$ continuation of chain reaction

and in the presence of ions (metals as a rule):

$ROOH + M^{+2} \rightarrow RO^{\bullet} + OH^{-} + M^{+3}$) acceleration of chain

$ROOH + M^{3} \rightarrow ROO^{\bullet} + H^{+} + M^{+2}$) reaction.

These and similar reactions lead to a polymerization or polycondensation of water solutions containing organic compounds, forming insoluble particles that precipitate from the water sediment. The mechanisms of this process is not fully understood. First of all is not clear whether in the process of precipitation is dominantly a physical process, e.g., change of zeta potential of colloidal particle, or chemical processes, removing the substances stabilizing the colloidal system. It has not been established, whether the colloidal particle charge has any part of the process of rediative water purification, and if the change has an effect on the behavior of micelle in the field of radiation, i.e., which one of the micelles is more amenable to radiation, the positively or the negatively charged ones?

SECTION 4

TEST PROCEDURES

Irradiation of Water Samples

The irradiation of water was carried out in a radiation chamber of a Russian production, RHM.-Gamma-20 (Figures 3 and 4). The system was comprised of a central chamber in a form of a cylinder of following dimensions:

- diameter 150 mm
- height 240 mm

and also six cylindrical side chambers of dimensions:

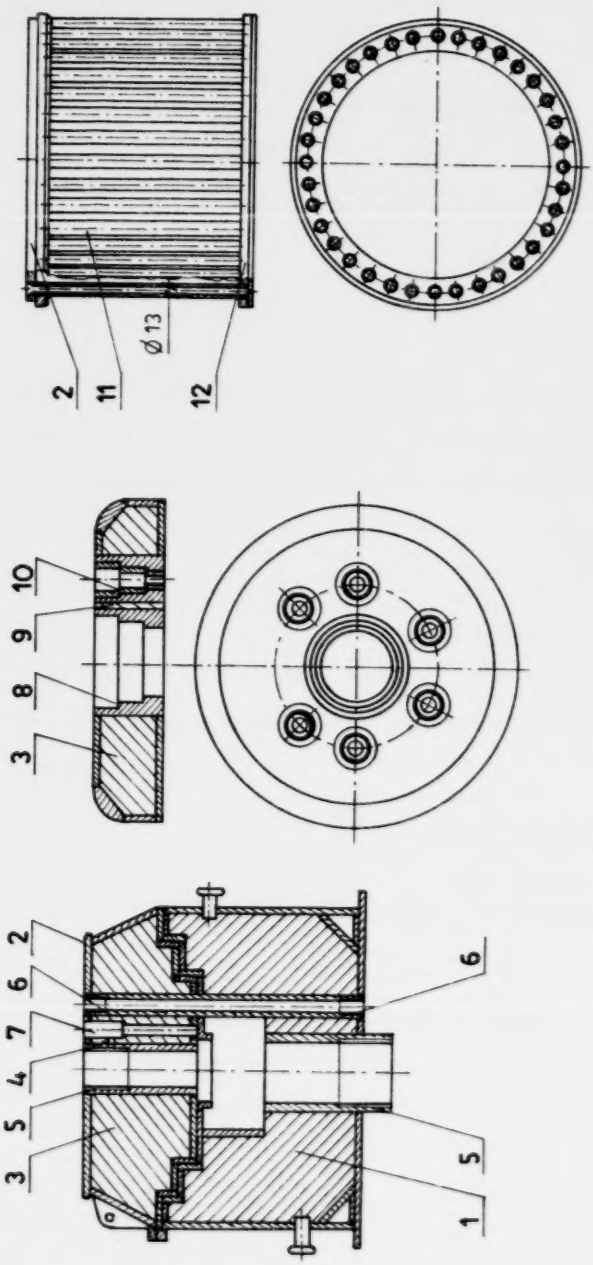
- diameter 60 mm
- height 220 mm

Source of radiation was cobalt, Co-60, with energy of gamma quanta 1.33; 1.17 McV.

A radioactive isotope is distributed around the central chamber in a special cassette containing 36 small tubes of 13 mm diameter. Each of these tubes contains 3 elements of Co-60 of dimensions:

- diameter 11 mm
- height 80.5 mm

Each tube contains about 341.5 Ci isotope.



Designations

1. Casing
2. Cover
3. Filling with lead
4. Central chamber
5. Bronze cylinder sleeve around central chamber
6. Bronze cylinder sleeve around side chamber
7. Channel to load the chamber with a radiation source
8. Graded cylinder sleeve of the central chamber
9. Side chamber
10. Graded cylinder sleeve of side chamber
11. Pipe with Co60 isotope
12. Basis.

Fig. 3. Radiation chamber type RHM - Gamma 20

The total activity of the installed source is about 12,300 Ci. A general picture of the chamber of radiations is shown in Figure 4.

The chamber allows the irradiation of the samples with the following exposure dose rates

- in the central chamber 800 kRad/hr.
- in a side chamber 200 kRad/hr.

The samples were irradiated in vessels made of soda glass with capacities:

- in central chamber 1000 ml
- in side chamber 300 ml.

Measurement of the Speed of Sedimentation

The basic parameter used to measure the effectiveness of radiation treatment was turbidity. Turbidity was measured in the samples at different time intervals starting from the time the sample was poured into a sedimentation cylinder. Changes in turbidity were measured with a spectrophotometric instrument, manufactured by Zeiss, type Specord UV VIS with a beam of light having a wavelength of 400 nm.

A relationship between light transmission (turbidity) and suspended matter was developed (Figure 5). The good agreement of this relastionship made it possible to make turbidity measurements instead of the more time consuming suspended matter in this study.

The Effect of pH

It was decided to study the rate of sedimentation as related to small changes in the pH of the initial solution.

The pH adjustment was made with 0.1 n HCl and 0.1 n NaOH. The pH values before and after the irradiation were measured with a pH meter of the Mining Electronics Works manufacture, type 7-A, with a range ensuring the accuracy of survey to $\pm$ 0.05 pH.

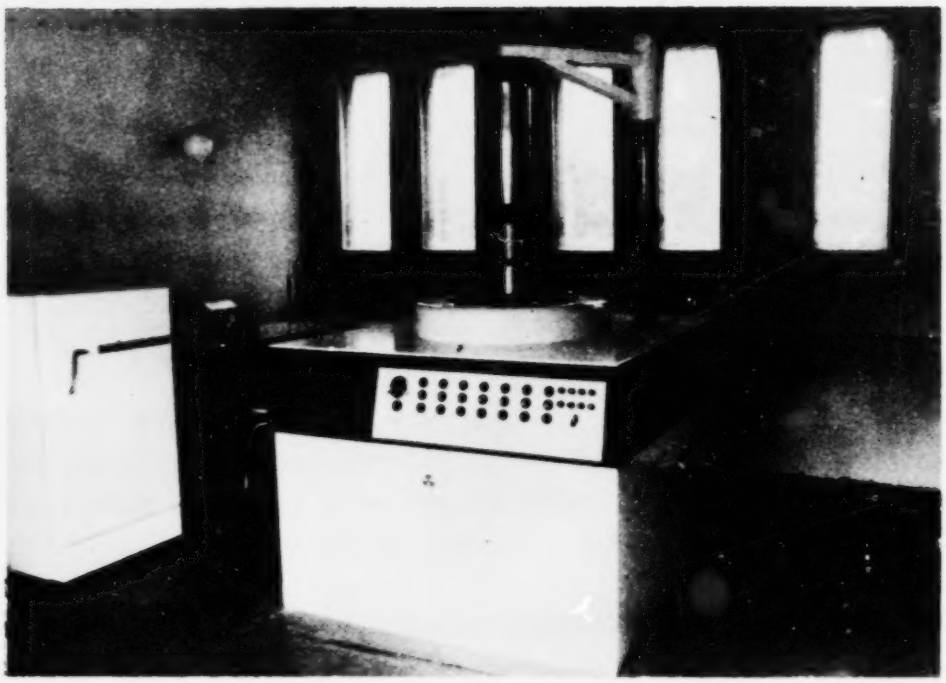


Fig. 4. Radiation chamber

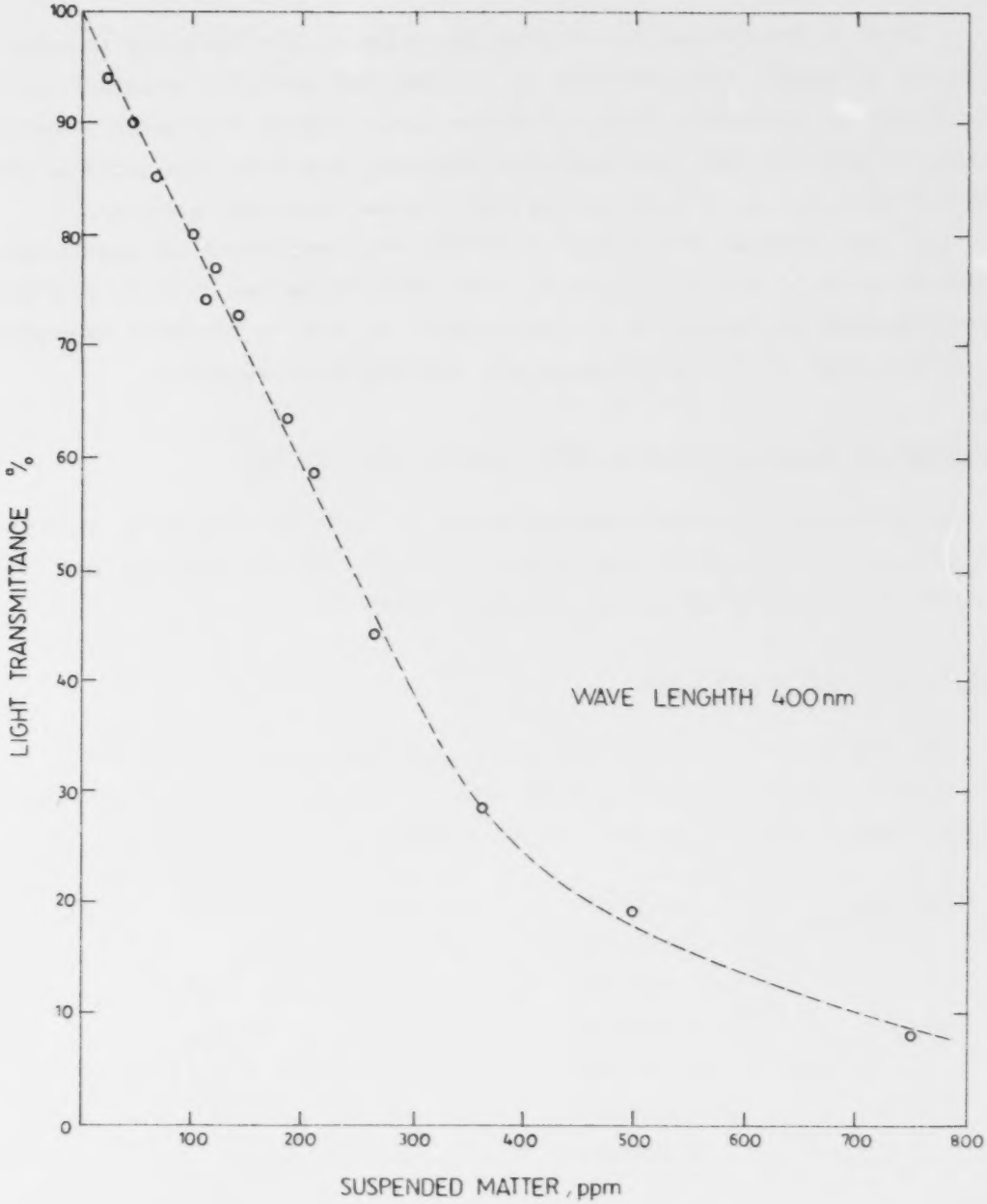


Fig. 5. Relationship Between Suspended Matter and Light Transmittance

Measurement of the "Zeta" Potential

From a theoretical basis one can expect the radiation to have an influence on the zeta potential of a colloidal particle, because of the ionization of particles. The generated ions should discharge electric fields connected with the colloidal particle, and thus the particle deprived of the charge should precipitate easier from the solution.

For this reason the "zeta" potential was measured on particles of colloidal coal in the water before and after radiation. The measurements were effected by means of a "Zetameter" of U.S. production operating on a principle of the electrophoretic mobility determination.

Changes in Oxygen Consumption and in Iron Content

In supplementing the measurements of turbidity and zeta potential, the changes in oxygen consumption or COD (permanganate) and iron content were evaluated using standard methods.

The Performed Operations

The tests were carried out on 7 samples of mine waters: 2 from the Turow and from Konin Mines, and 3 from Adamow Mine. These waters were collected on the following dates:

Adamow	-	I sample	on March 17, 1975
		II sample	on July 4, 1975
		III sample	on August 25, 1975
Konin	-	I sample	on April 21, 1975
		II sample	on September 22, 1975
Turow	-	I sample	on March 3, 1975
		II sample	on April 7, 1975

An analysis of the samples is shown in Table 1. All the water samples were subjected to the gamma radiation treatment in the radiation chamber with a higher intensity dose, 800 kRad/hr. The applied absorbed doses and the time of irradiation were:

Dose KRad	Low Intensity	High Intensity
100	30.0 min.	7.5 min.
500	150.0 min.	37.5 min.
1000	300.0 min.	75.0 min.
1500	450.0 min.	112.5 min.
2000		150.0 min.

In the irradiated waters the light transmission and the related suspended matter was evaluated as a function of time of sedimentation; the pH value (in some samples) before and after the radiation; the oxygen consumption after 4 hours of sedimentation in the Adamow water - sample I and II, and in Turow - sample I, and in the remaining samples at the end of sedimentation; on the iron content (in part of samples) - after 4 hours of sedimentation.

All the above measurements were carried out also in samples in which the pH was changed before the irradiation.

TABLE 1. CHEMICAL ANALYSIS OF COMPOSITIONS OF THE MINE WATERS

Determination	Unit	Adamow Sample III	Konin Sample II	Turow Sample II
Turbidity	mg/l SiO_2	400	18	600
Colour	mg/l Pt	20	30	75
Smell		Z2R	Z1R	Z1R
Oxygen Demand	mg/l O_2	74.0	5.6	45.0
Iron	mg/l Fe	7.3	2.0	4.6
Manganese	mg/l Mn	0.11	0.22	not confirmed
Sulphates	mg/l SO_4	107.8	43.2	348.6
Basicity	mval/l	4.0	7.0	4.8
Total Hardness	^{o}n	17.4	20.2	13.7
Calcium	mg/l Ca	79.3	96.1	61.6
Magnesium	mg/l Mg	39.0	32.2	23.9
Ammonia Nitrogen	mg/l N	0.47	2.8	not confirmed
Nitrite Nitrogen	mg/l N	0.015	0.015	0.075
Nitrate Nitrogen	mg/l N	0.48	0.48	0.64
General Dry Residue	mg/l	793	416	2275
General Dry Residue of Volatile Particles	mg/l	298	46	392
Dry Residue of Stable Particles	mg/l	495	370	1883
Total Dissolved Matter	mg/l	526	387	1490
Dissolved Volatile Matter	mg/l	229	41	214
Total Dissolved Solids	mg/l	297	346	1276
Total Suspended Matter	mg/l	267	29	785
Total Suspended Volatile Matter	mg/l	69	5	178
Total Suspended Solid Fraction	mg/l	198	24	607
Carbonate Hardness	^{o}n	11.2	19.6	13.4
Non-carbonate Hardness	^{o}n	6.2	0.6	0.3
Acidity	mval/l	6.05	0.1	0.15

SECTION 5

RESULTS

Results acquired from the tests are shown in Tables 2-14 and shown graphically in Figures 6-39 in the Appendix.

An analysis of the results showed that sedimentation of the suspended solids for the tested waters was increased by Co-60 gamma radiation treatment. The effect from a practical point of view is observed starting from the absorbed dose of 500 kRad.

A change in the rate of sedimentation also occurred with an adjustment in pH before the irradiation. In some cases in improvement in the effect of radiational sedimentation was noted. This improvement took place in samples with only a small decrease in pH.

Samples, in which the pH value was measured before and after the irradiation indicate that the radiation caused a decrease in the pH of the tested waters. The change in pH is subject to the quantity of the absorbed dose, and the decrease in pH is greatest within the 300-1.000 kRad range. For the same absorbed doses an equal decrease in pH is achieved independent of whether the sample was irradiated with a 200 or an 800 kRad intensity.

The effect of the sedimentation rate increase is to the related absorbed dose amount. This condition as a rule is directly proportional. The greatest changes in the rate of sedimentation occurred under the influence of radiation in waters with a naturally large COD (Turow: samples I and II; Adamów: sample III).

The dependence of the increased sedimentation effect on the absorbed dose amount is in agreement with theory since the water radiolysis should be similar and the radiochemical processes should intensify with the increased doses.

The radiation affected only slightly the zeta potential of the suspended colloidal particle. The observed changes are difficult to explain and depend probably on the absorbed dose on the intensity of dosing and on the chemical composition of the water. In no case was a decisive change in zeta potential observed, especially one that would lead to an increase in the sedimentation of colloidal suspensions.

The COD of the tested waters, as opposed to the zeta potential, was decreased appreciably after a radiation treatment. This change increased with increase in absorbed dose amount. It is apparent in waters with a high natural COD that the fastest removal of suspended solids under radiation effect was observed.

Summing up, from the results obtained from the research it can be stated that a radiative treatment of waters drained from lignite open pit mines gave positive results beginning with a dose about 500 kRad. One could adopt a 1.000 to 2.000 kRad, dose but the increase in the rate of purification is not efficient in terms of the additional energy input.

No definite influence was seen regarding the quantity of pollutants on the rate of suspended matter removal under an exerted influence of radiation. It was characteristic that the tested waters differed in this respect considerably (see results for Turow I and Adamow II or Konin II). In one case it was found that the kind of pollutants may have an influence on the rate of the precipitation. Comparing the contents of suspended matter and dissolved substances in the Turow water tests with the rate of radiation purification, it can be seen that it was not the quantity of the suspended matter but the dissolved substances that

influenced the rate. This finding is tentative and would require further research to verify. Further work would also be necessary to determine which of the dissolved elements has such an influence.

The sensitivity of a radiation purification efficiency on the chemical properties of water is confirmed by the data showing the influence of COD. The greatest impact of radiative purification is achieved in waters with a high COD.

The mechanism of radiative purification is based probably on chemical transformations. A reduction in pH and COD is obtained, however no significant changes are observed in the "zeta" potential.

In this project no detailed analysis was performed on the technical feasibility or cost to take the technology to pilot or full scale. The discussion not to carry the studies further was based on the results from four tests and after consultations with American specialists who felt the economics of the system under United States conditions were not feasible and the acceptance of such a system by American industry was not likely. In addition research in other purification methods held greater potential for application in the United States.

If the process is to advance to full scale, then consideration should be made whether it is best to irradiate with sedimentation or separately.

To answer this question, the costs, efficiency and advisability of each method must be considered. An optimum dose could be supplied in an installation that operated cyclic or continuous flow. A cyclic system could be relatively small and therefore cheap, but has technical inconveniences (halting of flow, required attendance, sediment removal, small output), thus this system would probably only be useful in an experimental installation. For an industrial installation the continuous flow made would be best. A larger source of radiation would be needed and the investment costs would be greater. A partial reduction of costs is achieved through the elimination of labor requirements. In designing a continuous flow system combined irrariation and sedimenta-

tion in one reservoir should be avoided. This method would create a difficult problem of sediment removal in the field of radiation. Instead a separate chamber should have hydraulic flow conditions that limit the settling of suspended solids.

Finally a significant reduction in the source activity could be achieved performing the process of radiative purification in combination with a chemical one. This method would be perhaps less successful than the pure radiative purification, but from the mechanism of the process standpoint, it would lead to a significant augmentation in output of purification through the synergy of both processes.

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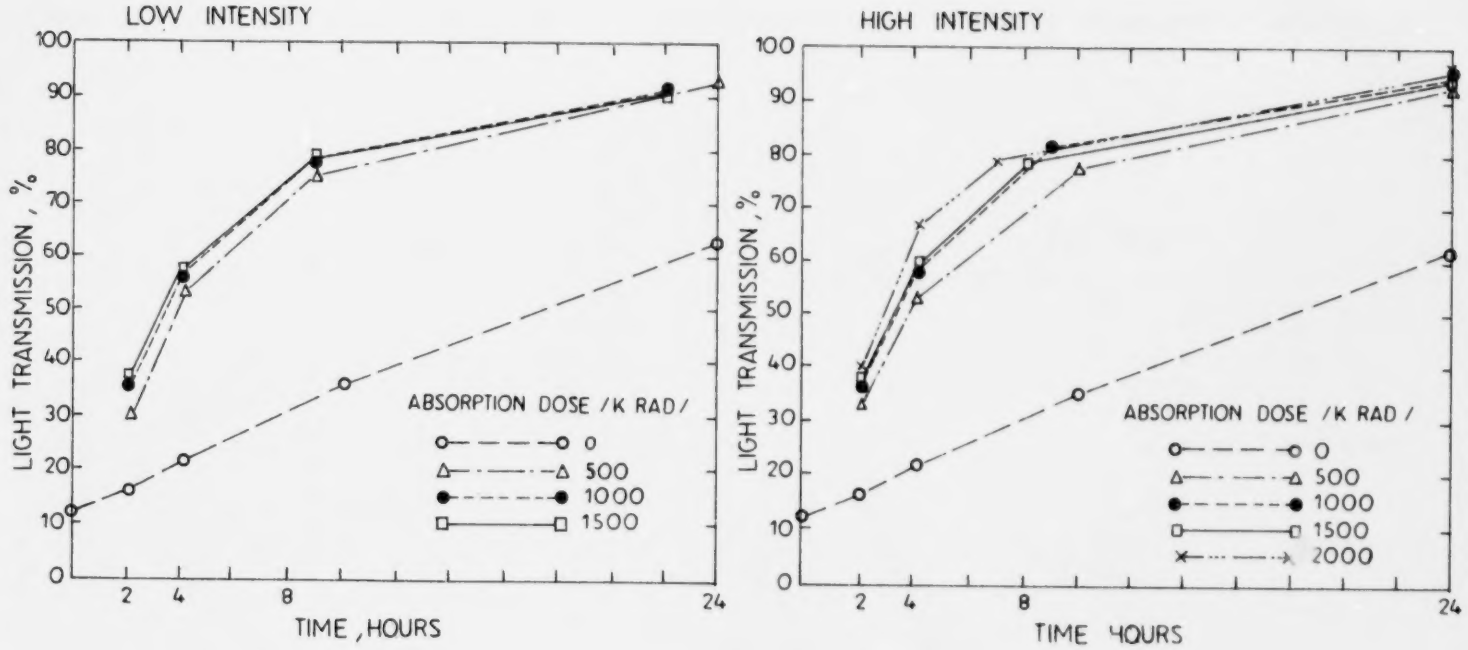


Figure 6. Radiation application effect on light transmission. Adamów mine water. Sample III, pH-7.45

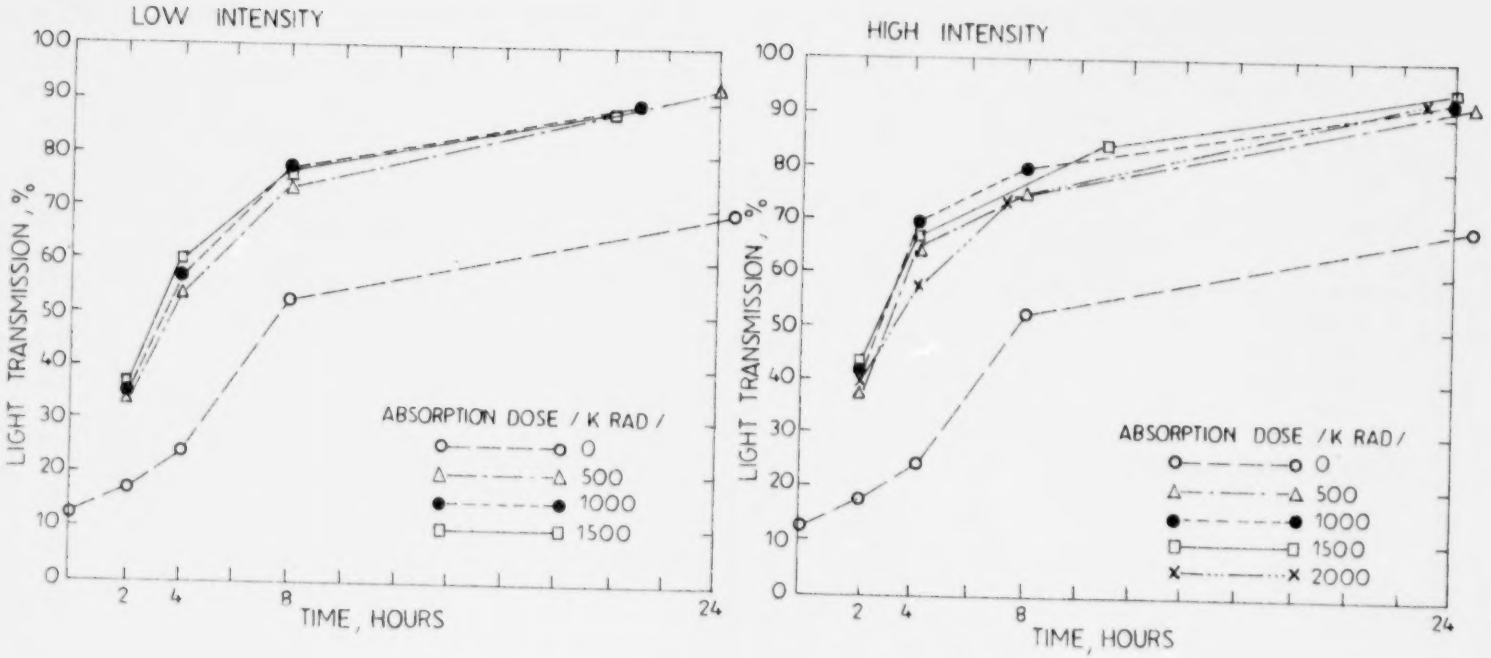


Figure 7. Radiation application effect on light transmission. Adamów mine water. Sample III, pH-7.72

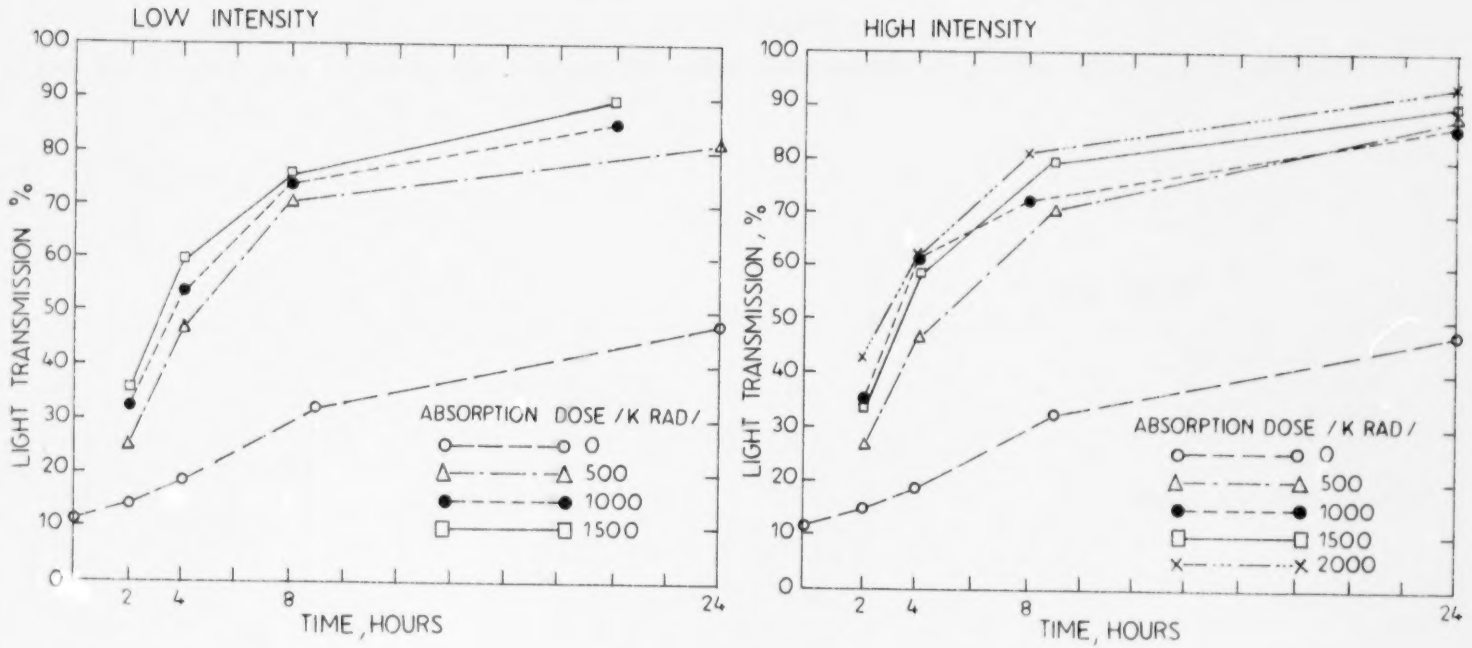


Figure 8. Radiation application effect on light transmission. Adamów mine water. Sample III, pH-8.13

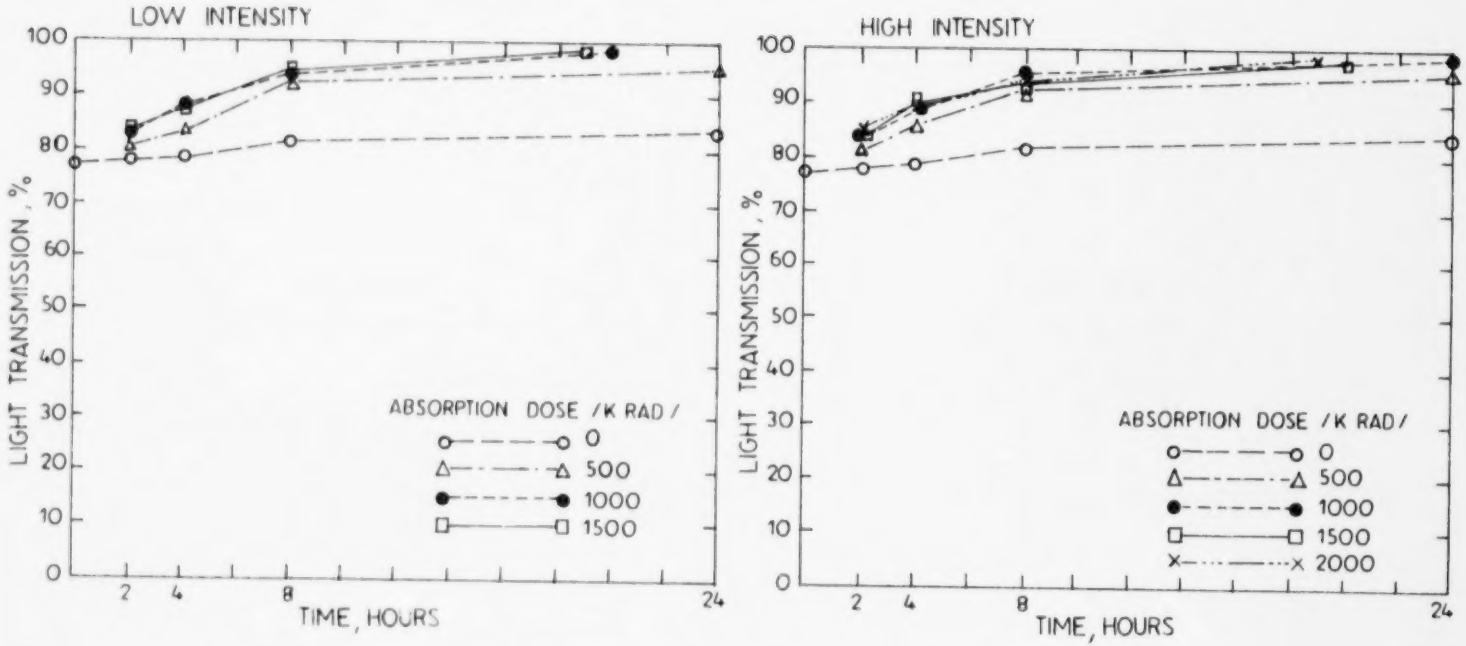


Figure 9. Radiation application effect on light transmission. Konin mine water. Sample II, pH-7.43

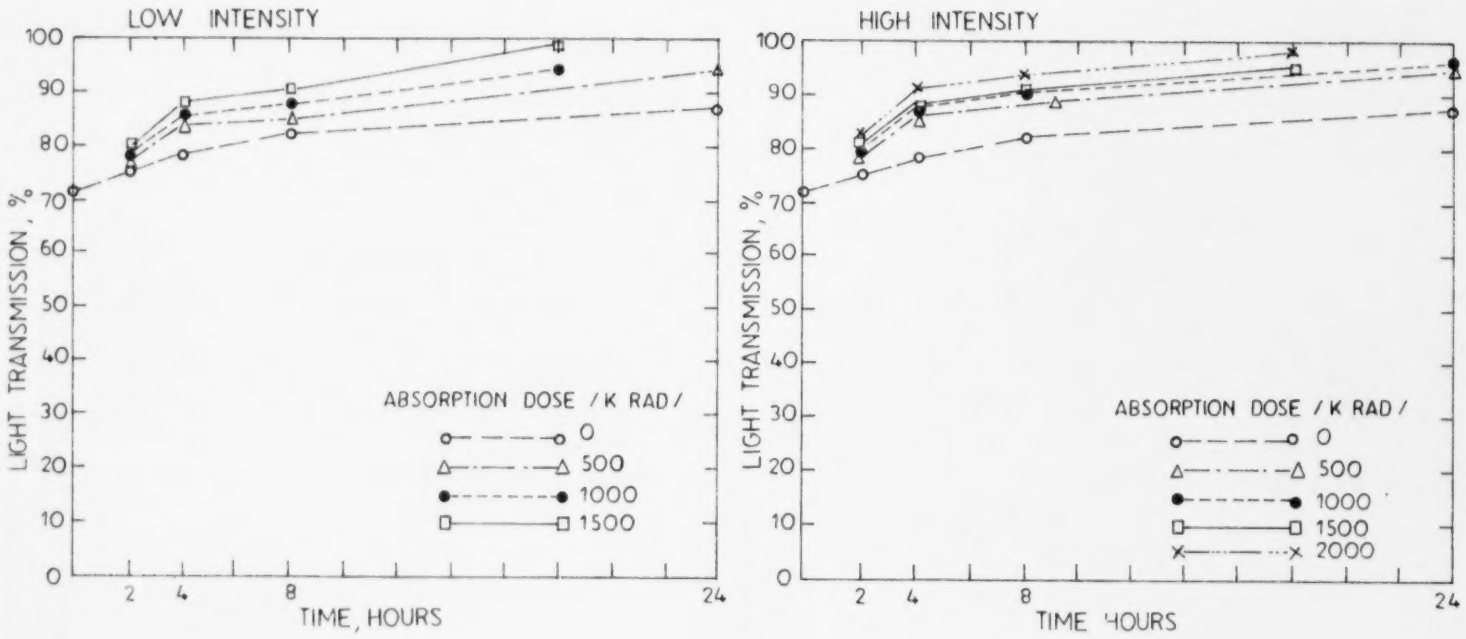


Figure 10. Radiation application effect on light transmission. Konin mine water. Sample II, pH-7.86

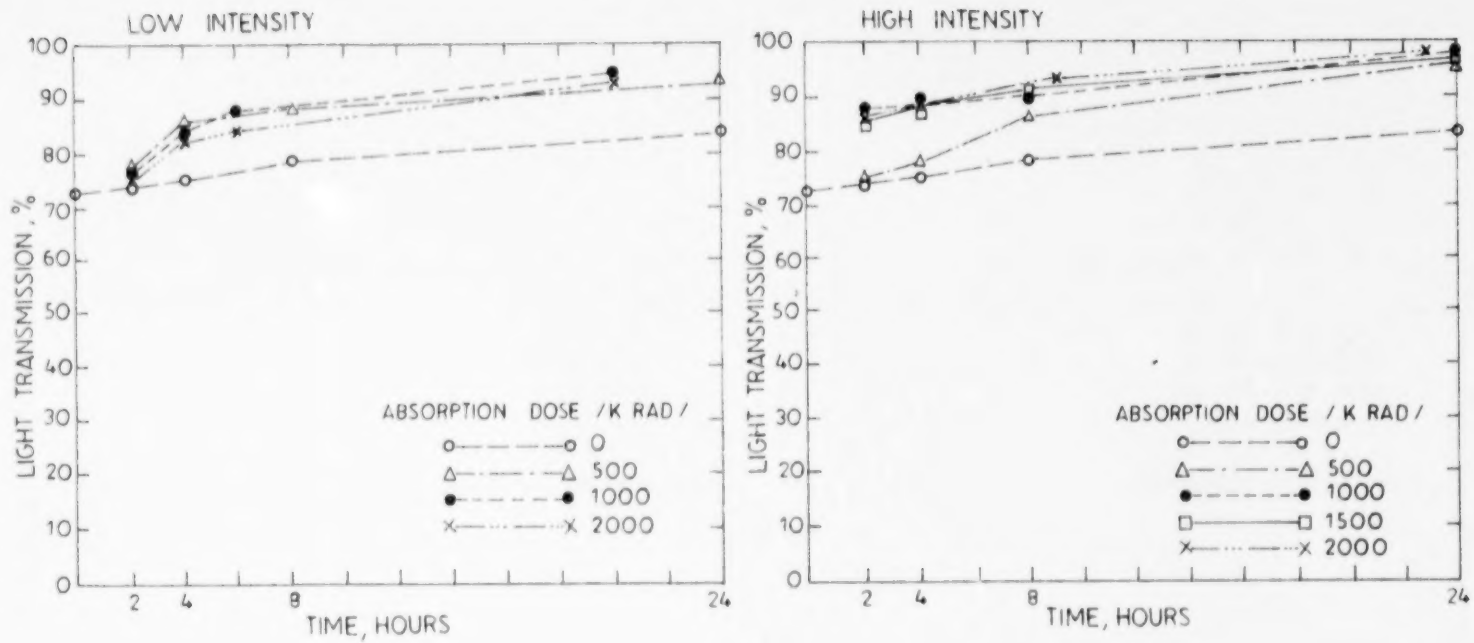


Figure 11. Radiation application effect on light transmission. Konin mine water. Sample II, pH-8.11

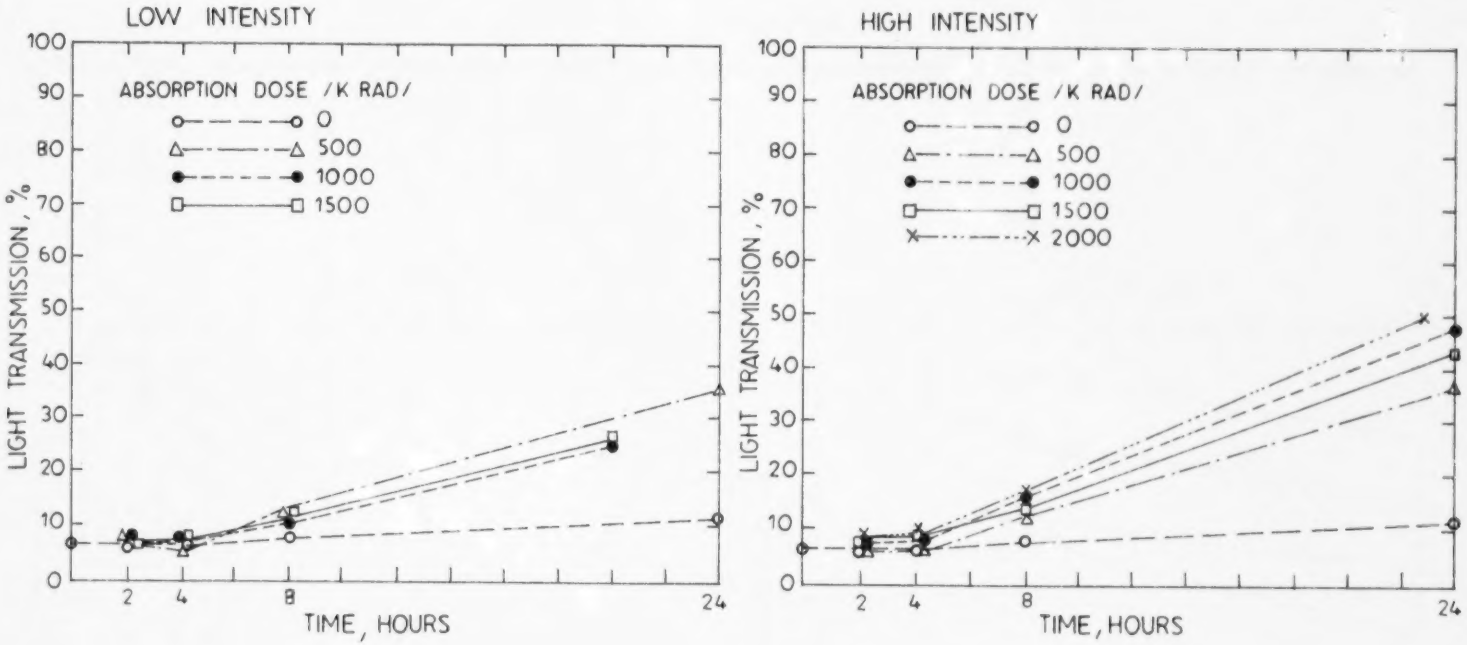


Figure 12. Radiation application effect on light transmission. Turów mine water. Sample II, pH-7.78

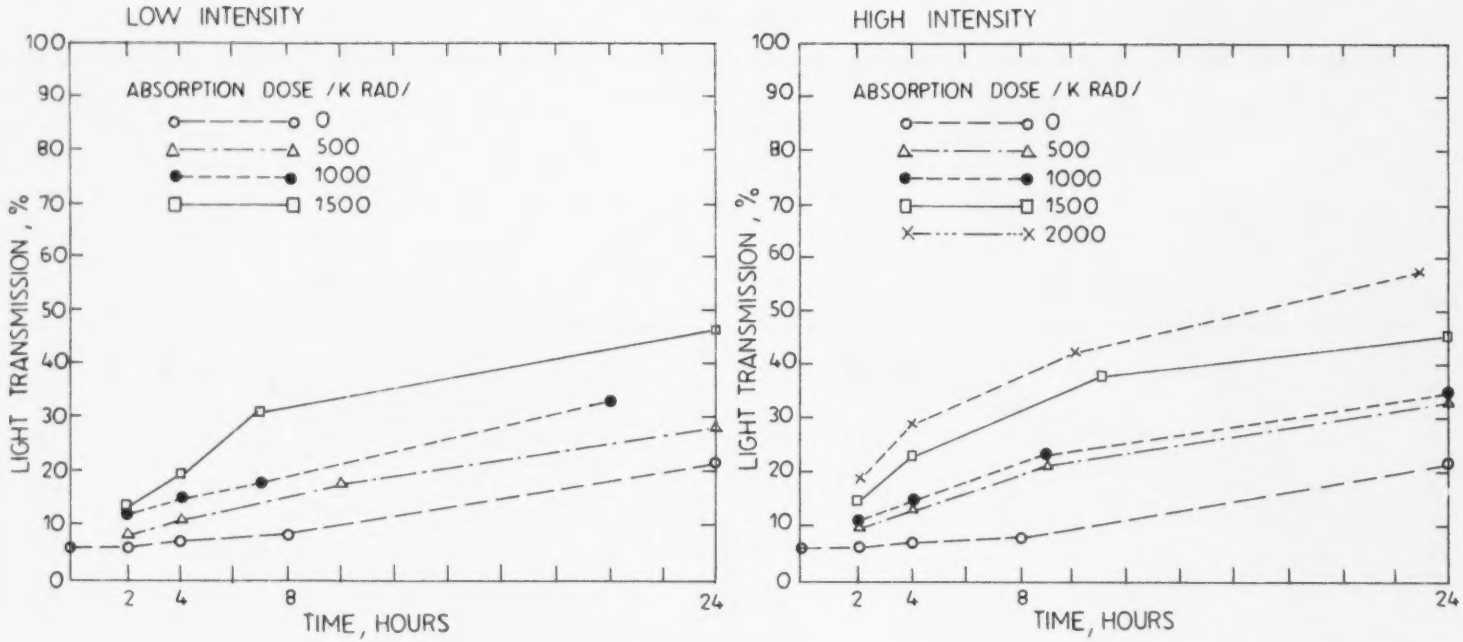


Figure 13. Radiation application effect on light transmission. Turów mine water. Sample II, pH-7.94

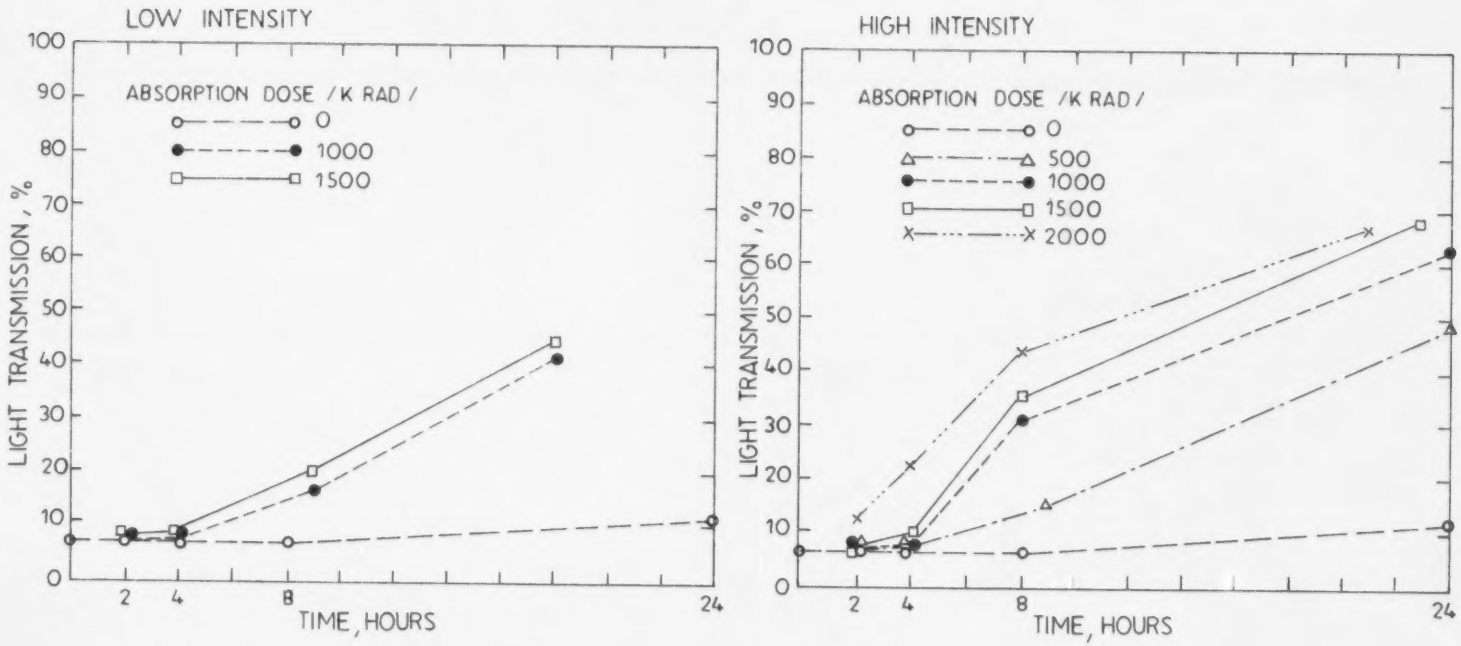


Figure 14. Radiation application effect on light transmission. Turów mine water. Sample II, pH-8.24

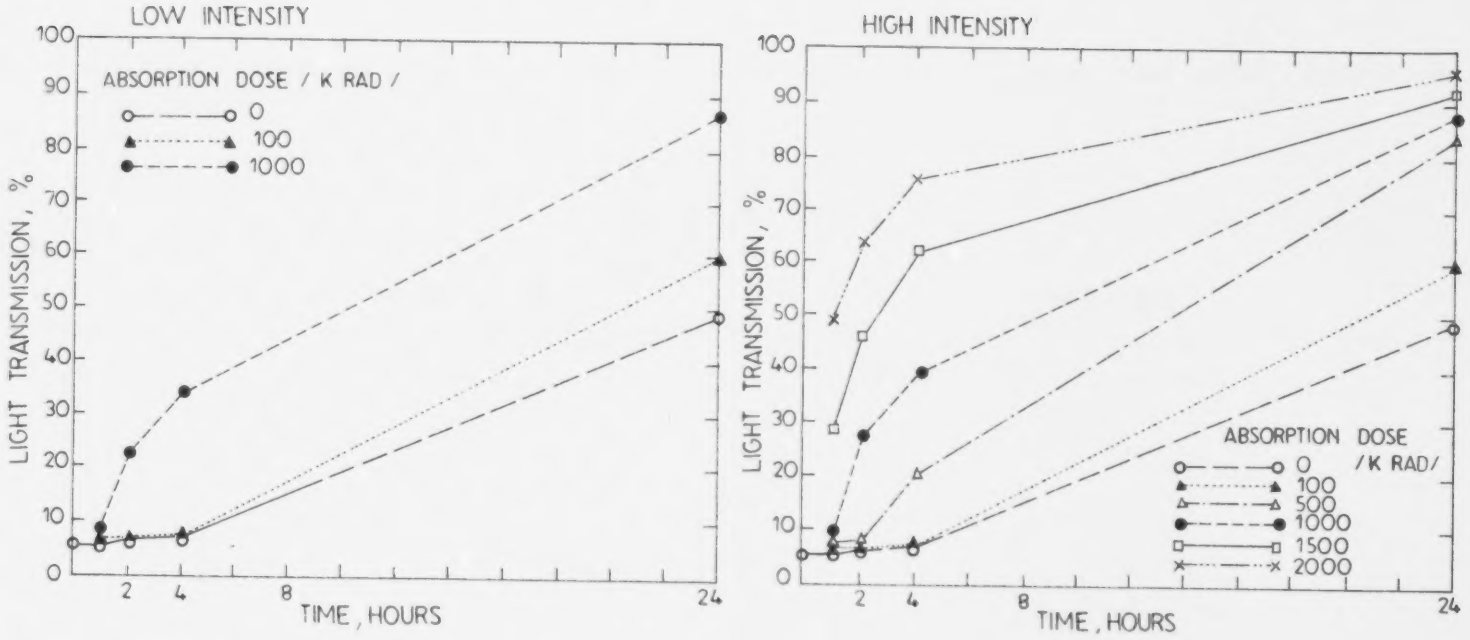


Figure 15. Radiation application effect on light transmission. Turów mine water. Sample II, pH-7.4

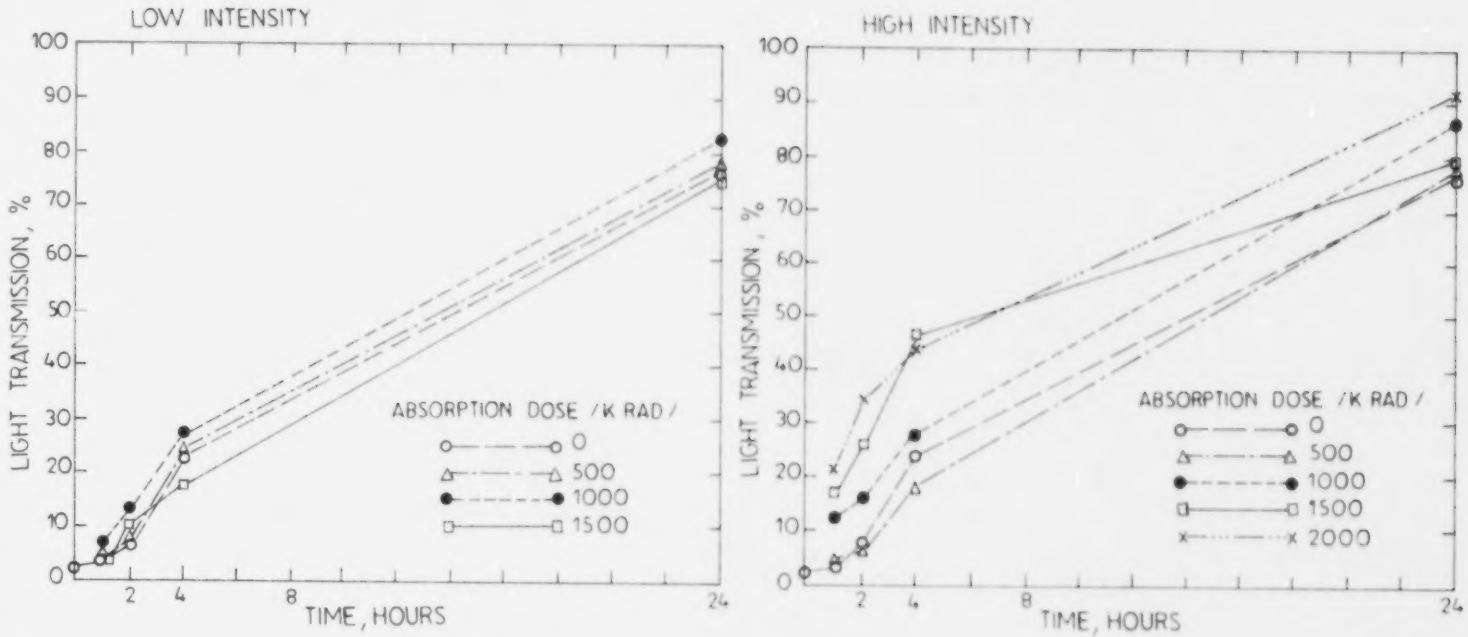


Figure 16. Radiation application effect on light transmission. Turów mine water. Sample II, pH-9.5

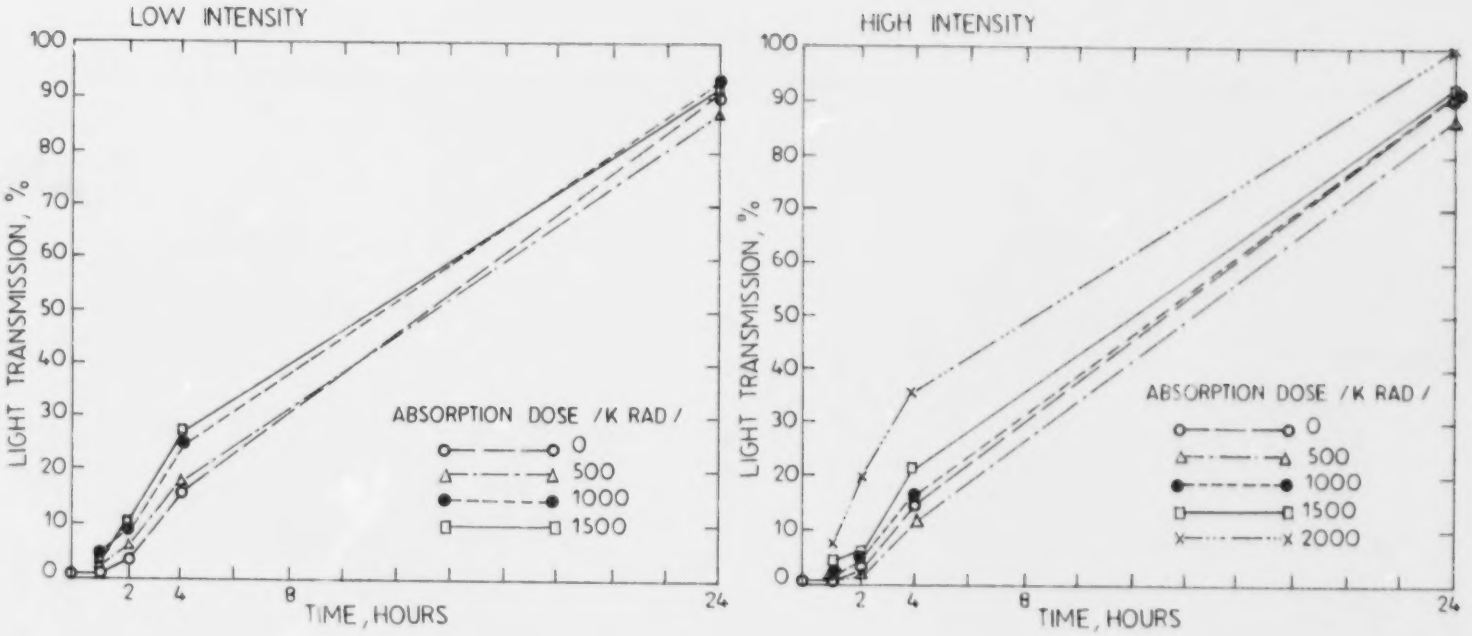


Figure 17. Radiation application effect on light transmission. Turów mine water. Sample II, pH-5.5

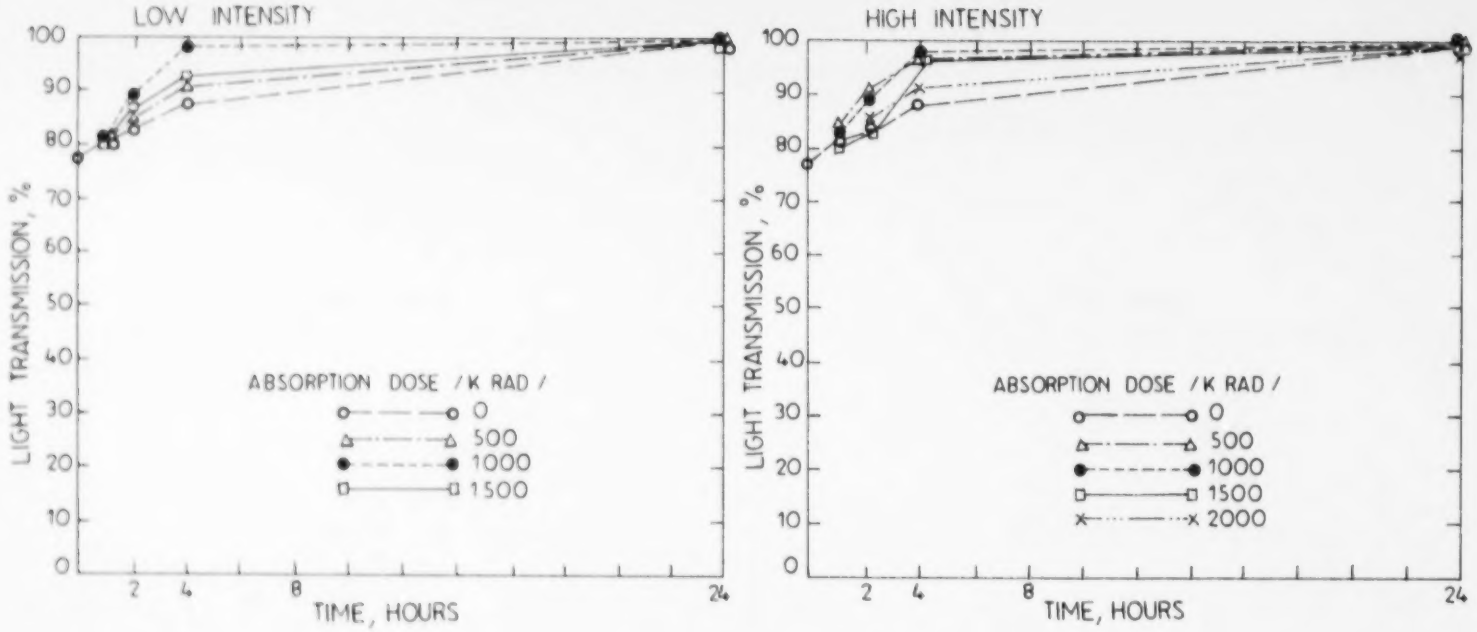


Figure 18. Radiation application effect on light transmission. Adamówmine water. Sample III, pH-7.75

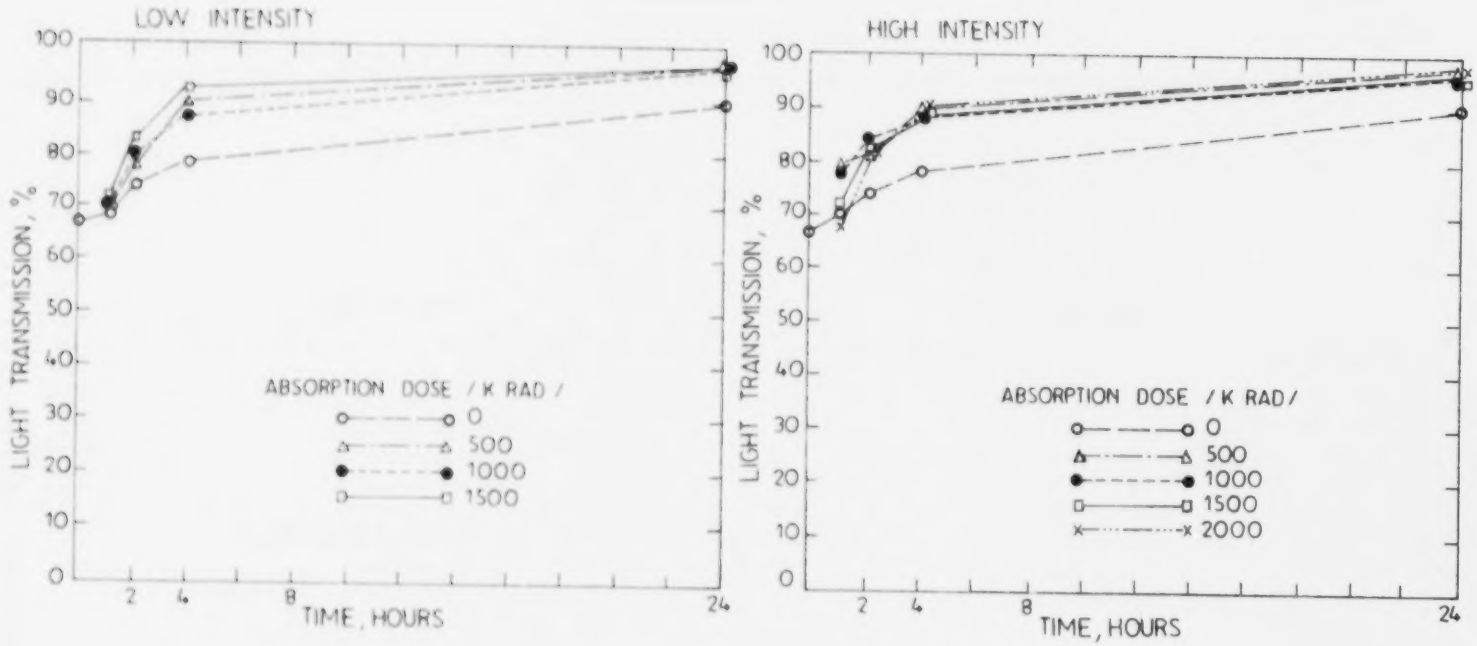


Figure 19. Radiation application effect on light transmission. Adamów mine water. Sample III, pH-9.0

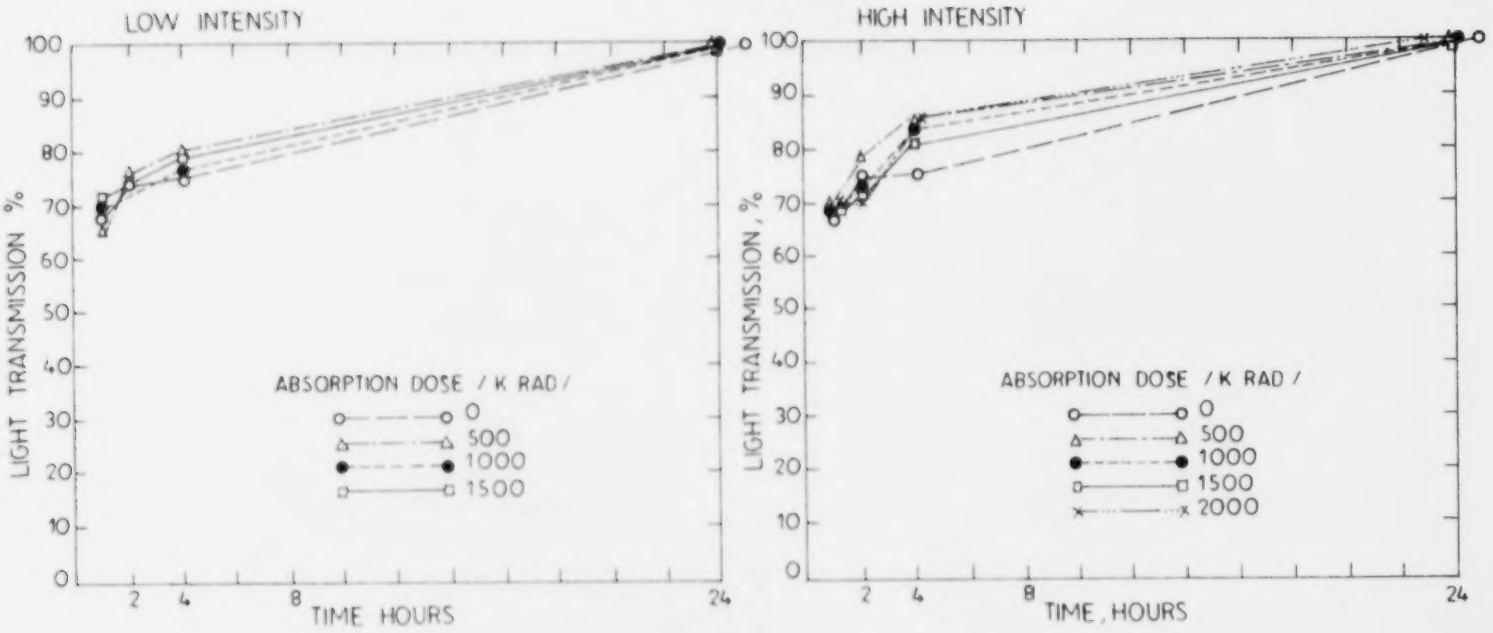


Figure 20. Radiation application effect on light transmission. Adamów mine water. Sample III, pH-7.0

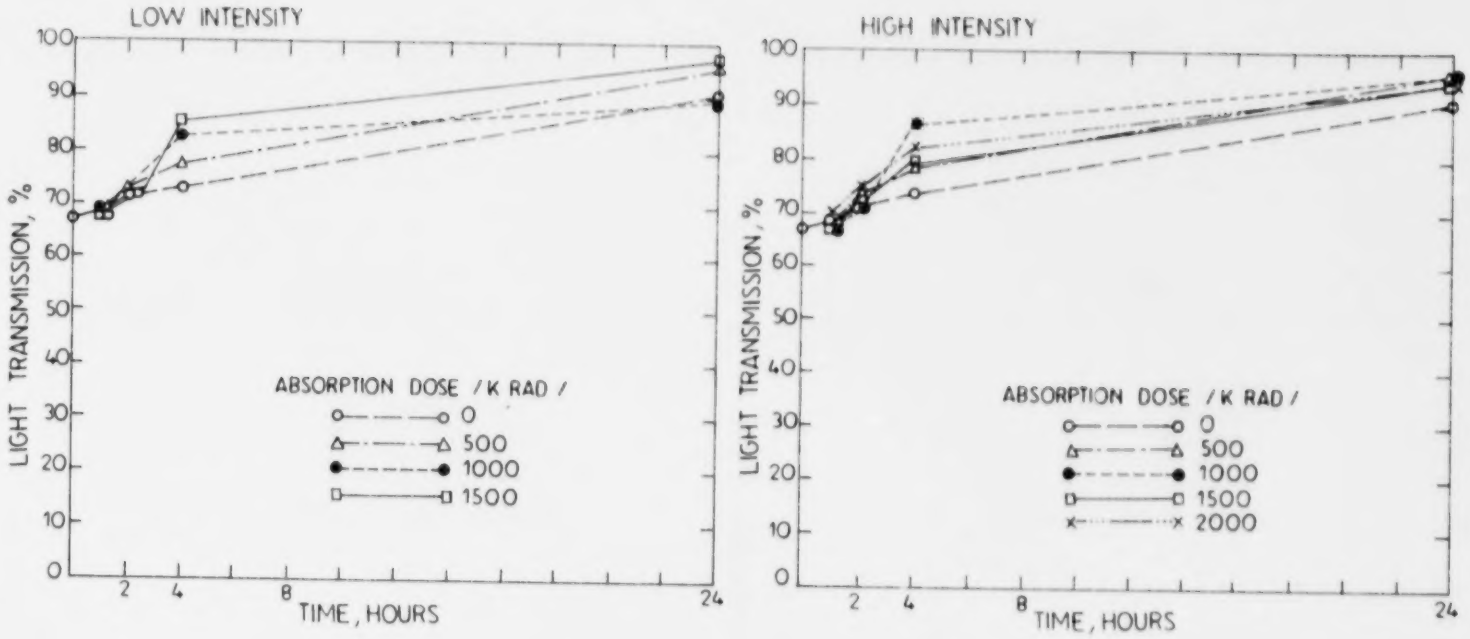


Figure 21. Radiation application effect on light transmission. Adamów mine water. Sample III, pH- 6.0

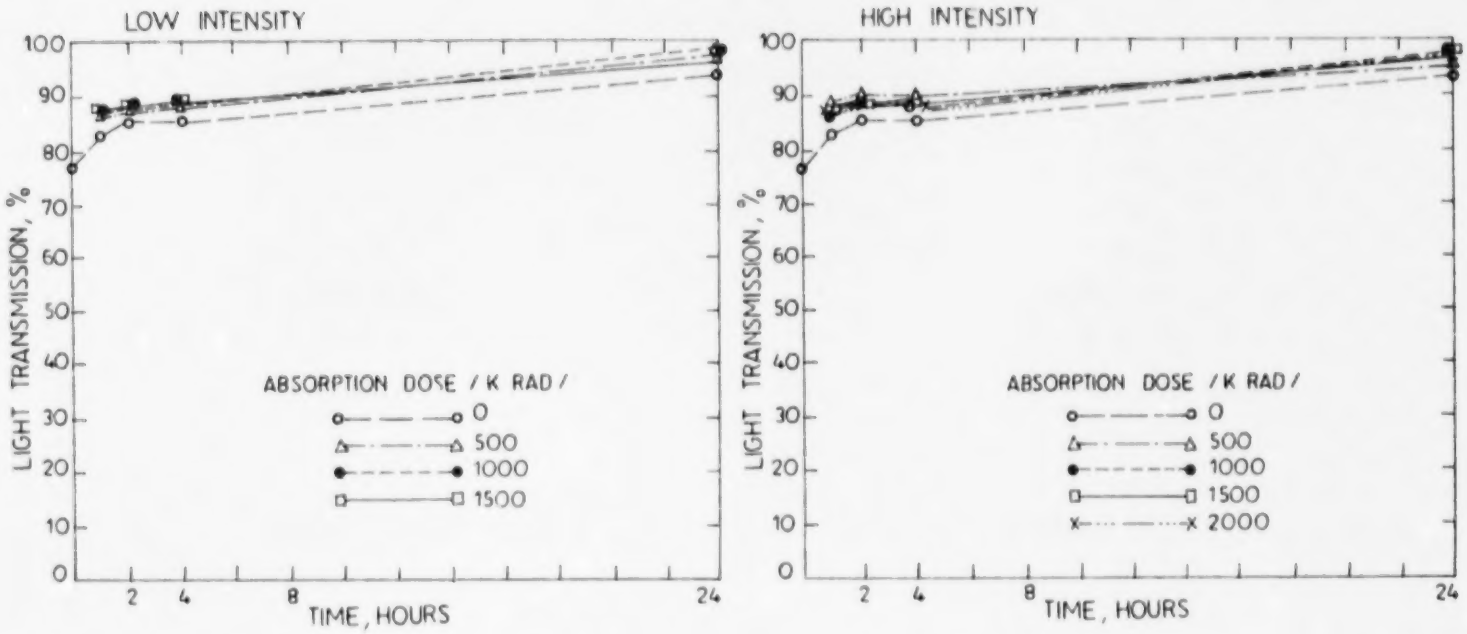


Figure 22. Radiation application effect on light transmission. Adamów mine water. Sample IV, pH-7.45

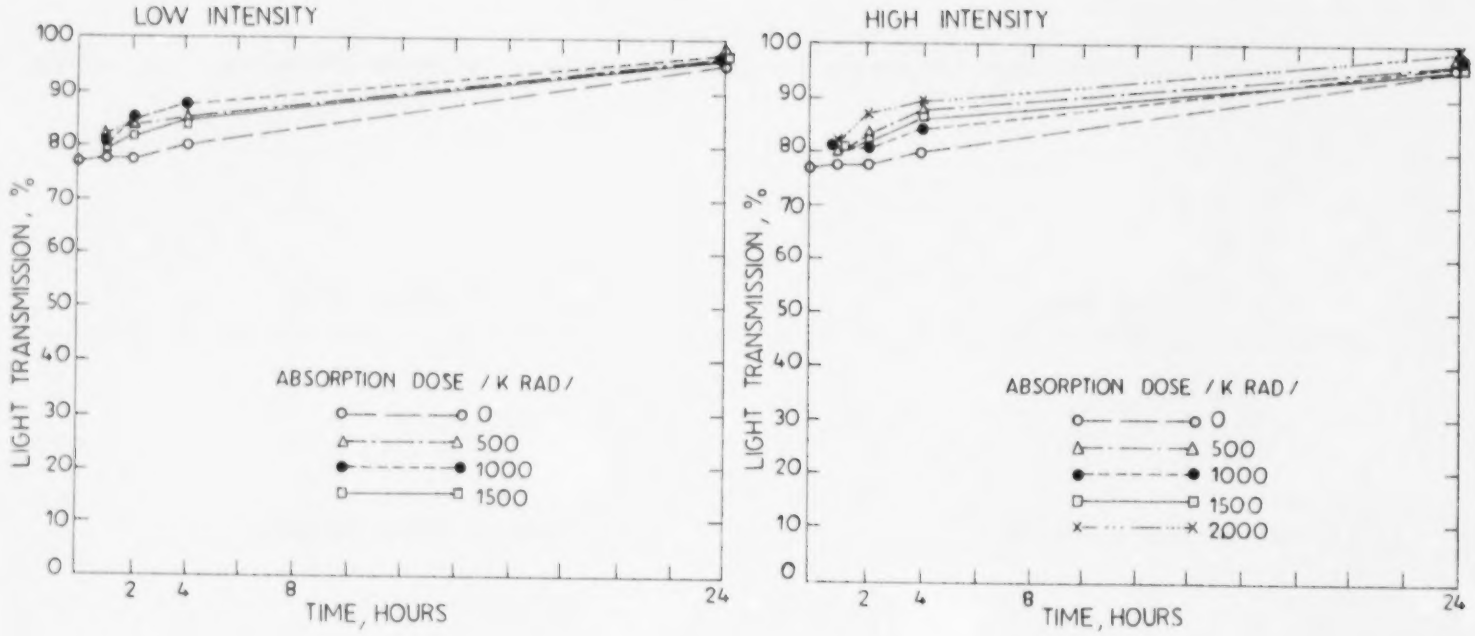


Figure 23. Radiation application effect on light transmission. Adamów mine water. Sample IV, pH-7.85

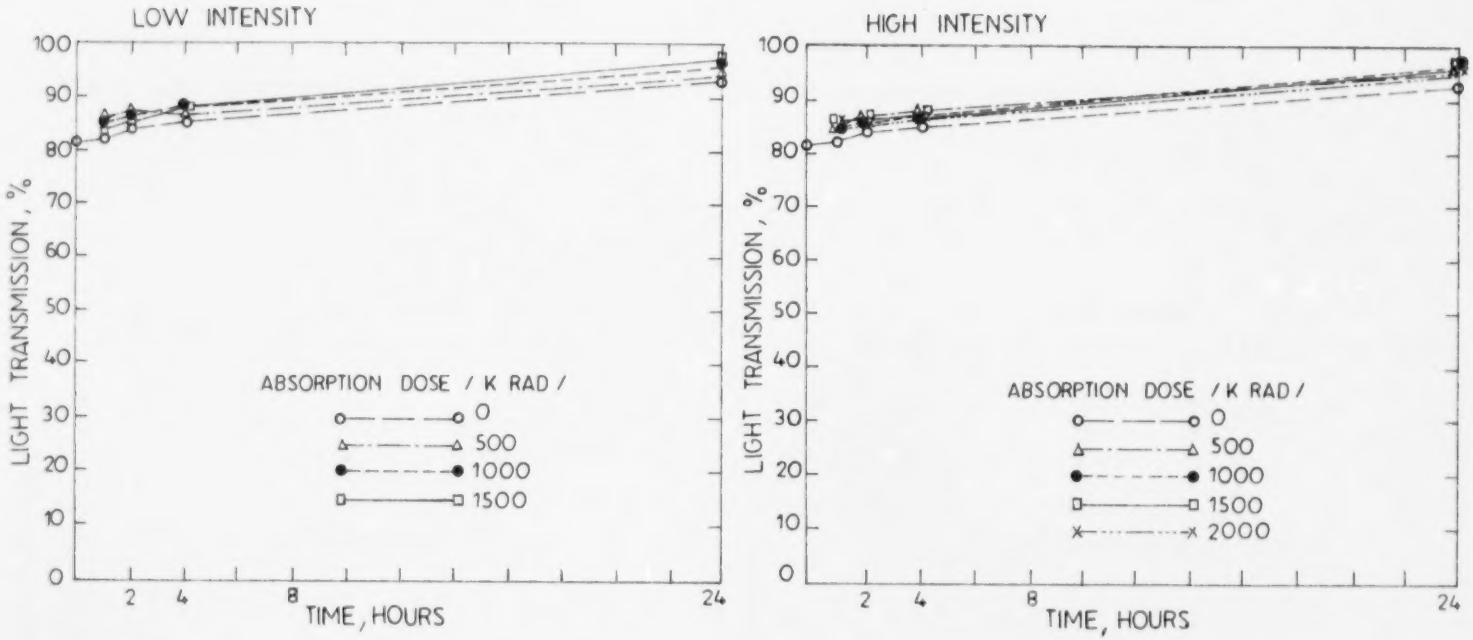


Figure 24. Radiation application effect on light transmission. Adamów mine water. Sample IV, pH-8.1

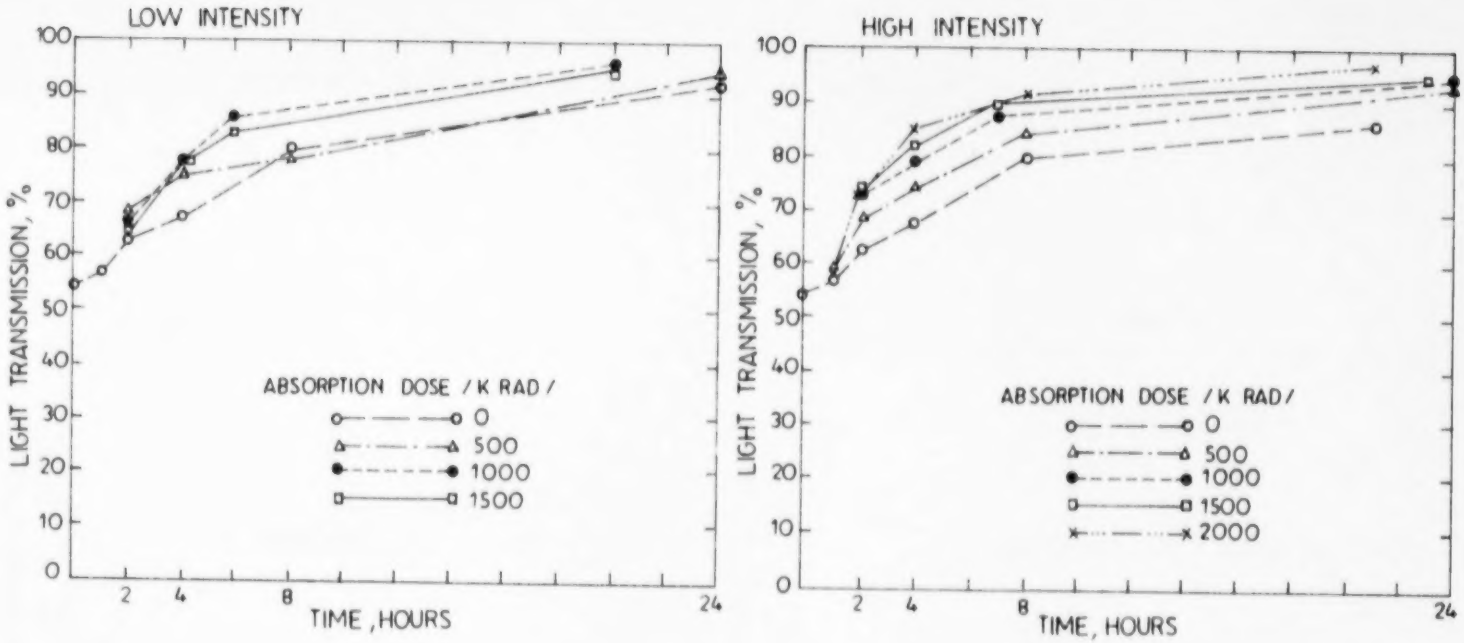


Figure 25. Radiation application effect on light transmission. Konin mine water. Sample V, pH-7.83

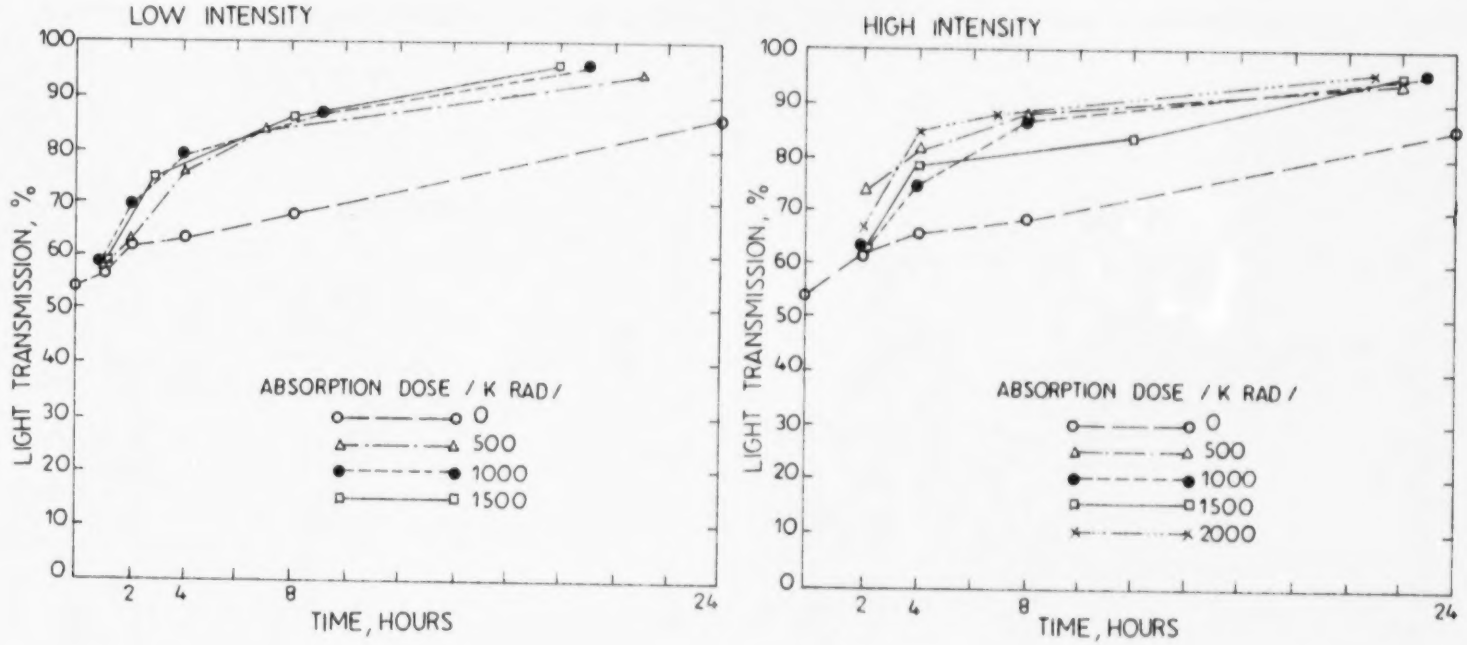


Figure 26. Radiation application effect on light transmission. Konin mine water. Sample V, pH-7.55

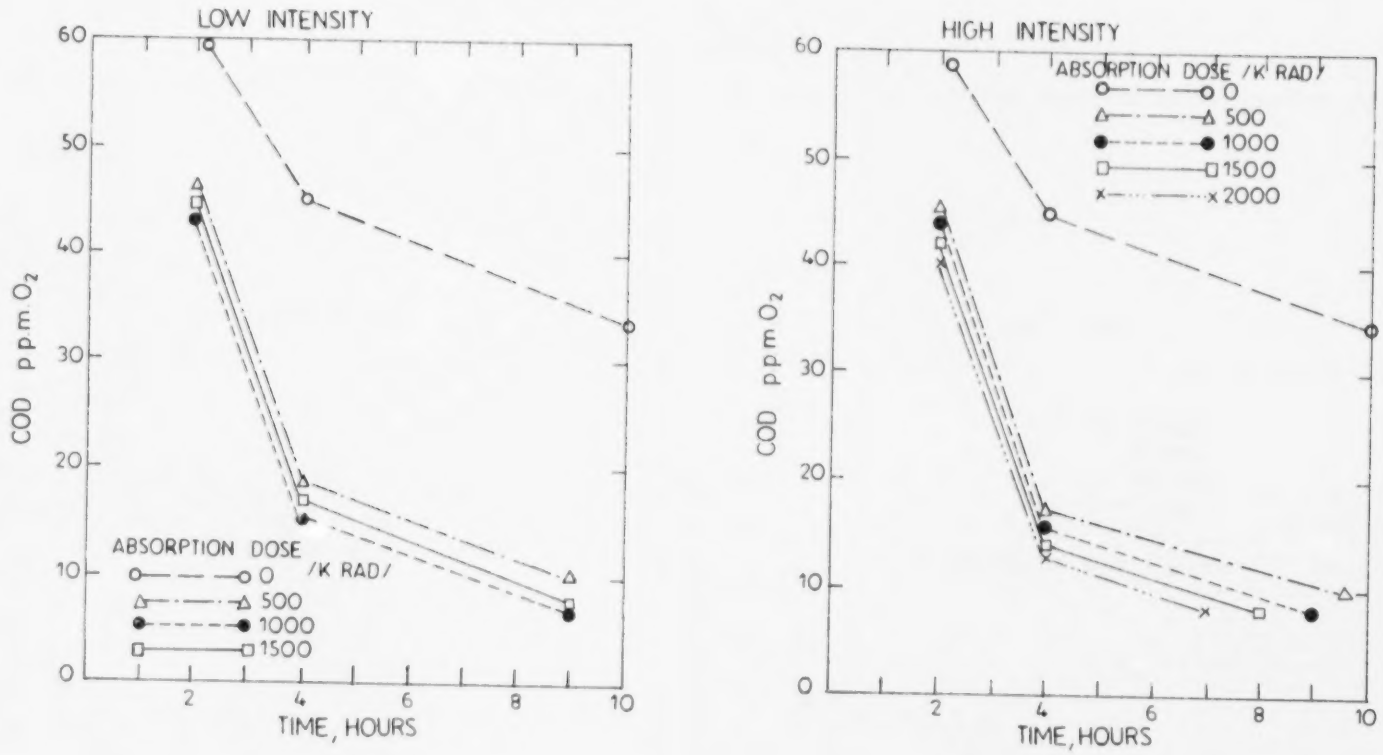


Figure 27. Radiation application effect on COD. Adamów mine water. Sample III, pH-7.45

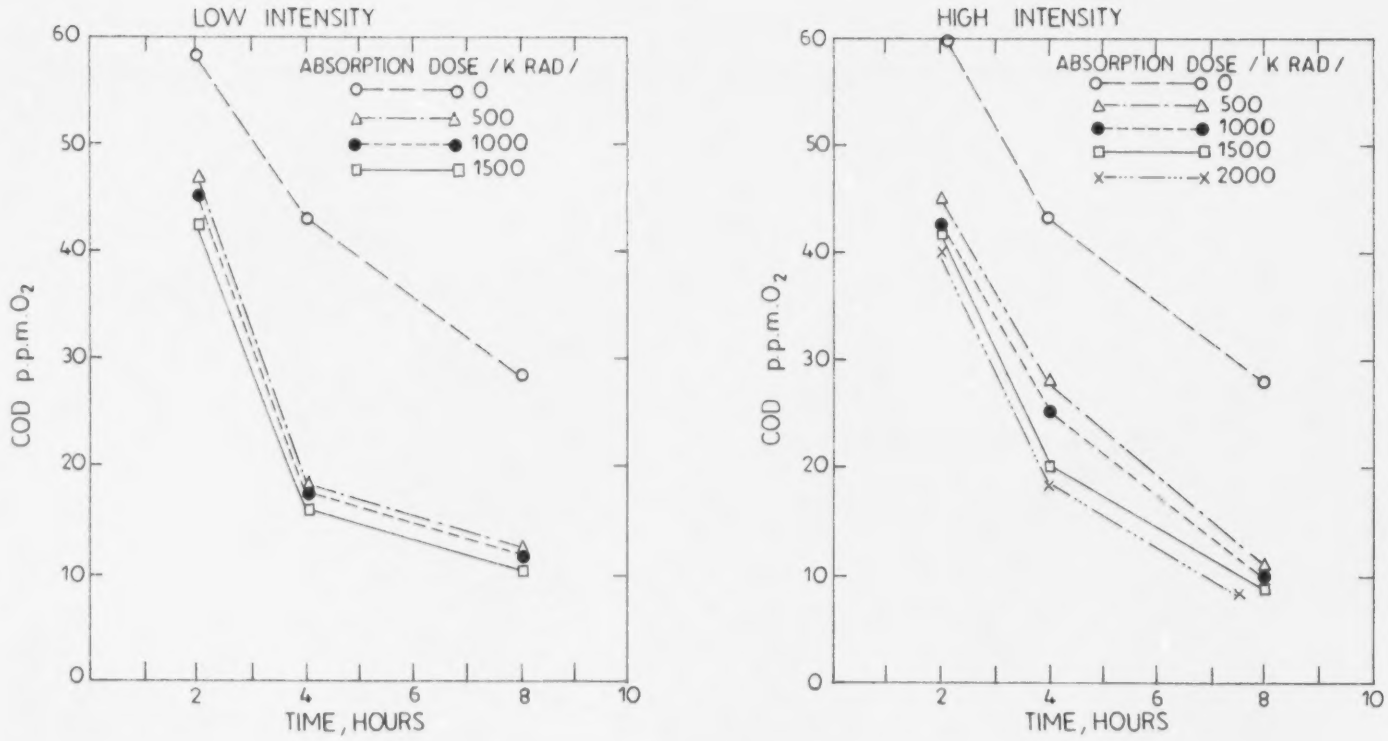


Figure 28. Radiation application effect on COD. Adamów mine water. Sample III
pH-7.72

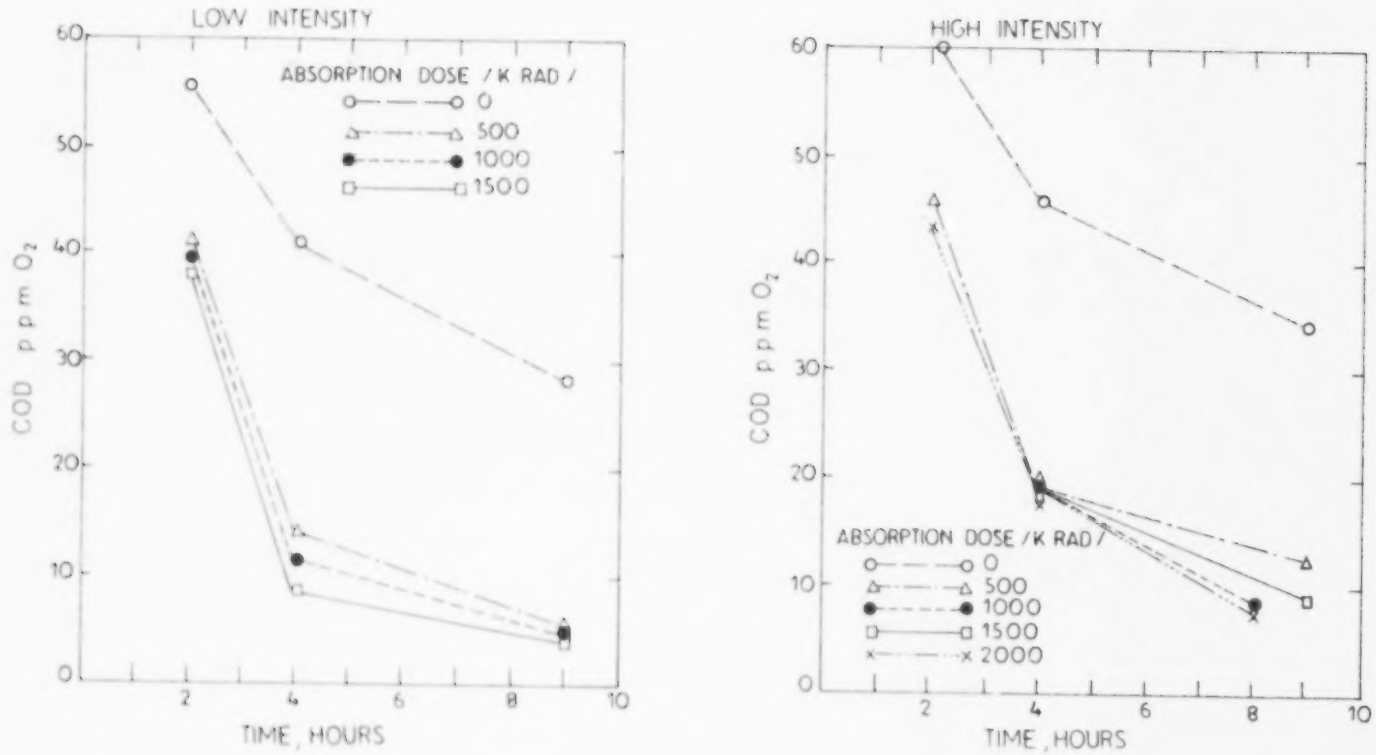


Figure 29. Radiation application effect on COD. Adamów mine water. Sample III, pH-8,13

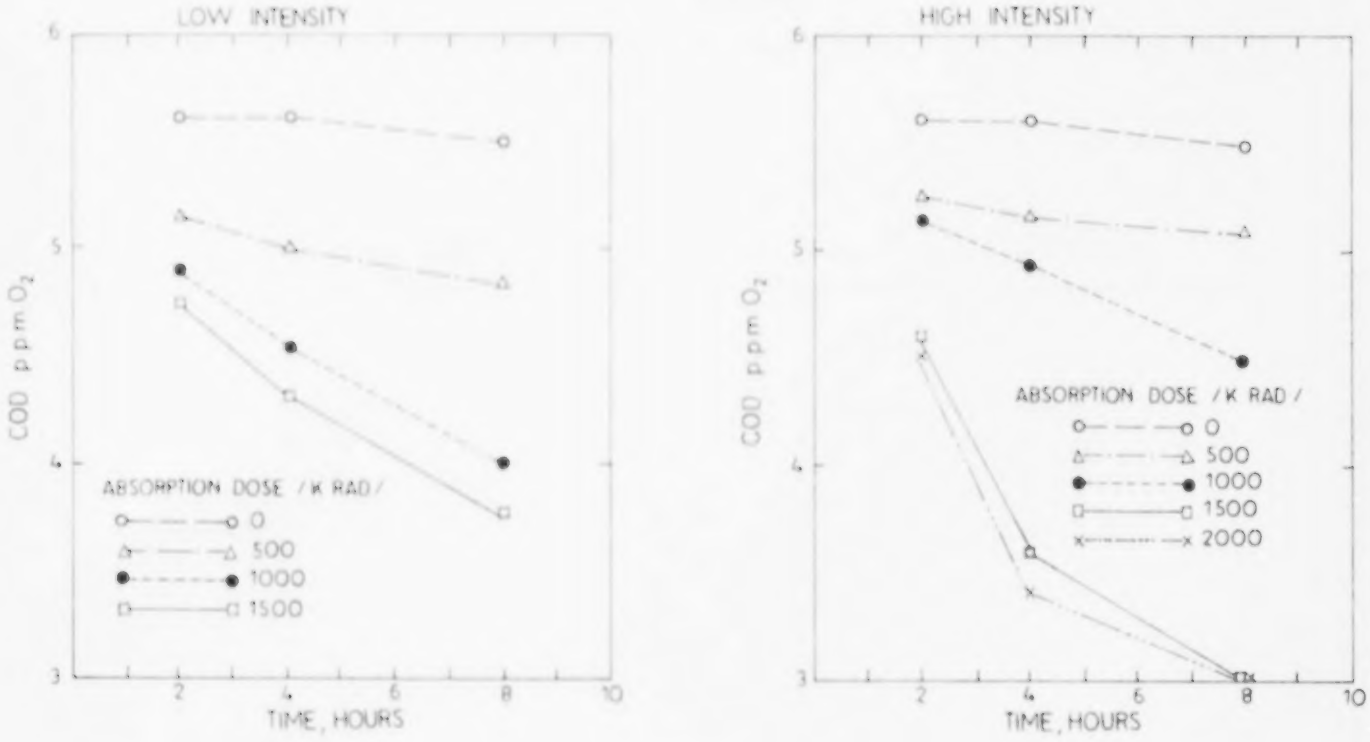


Figure 30. Radiation application effect on COD, Konin mine water, Sample II, pH-7.43

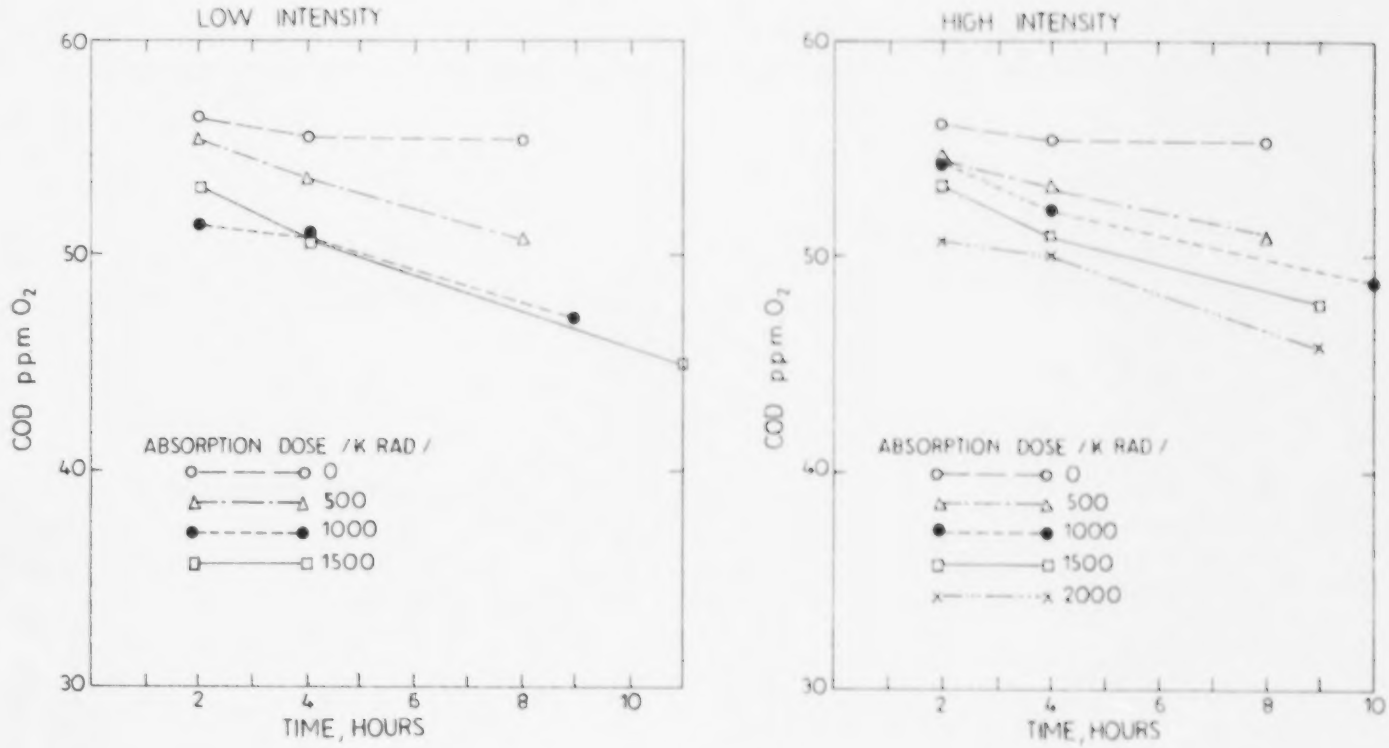


Figure 31. Radiation application effect on COD, Konin mine water, Sample II, pH-7.86

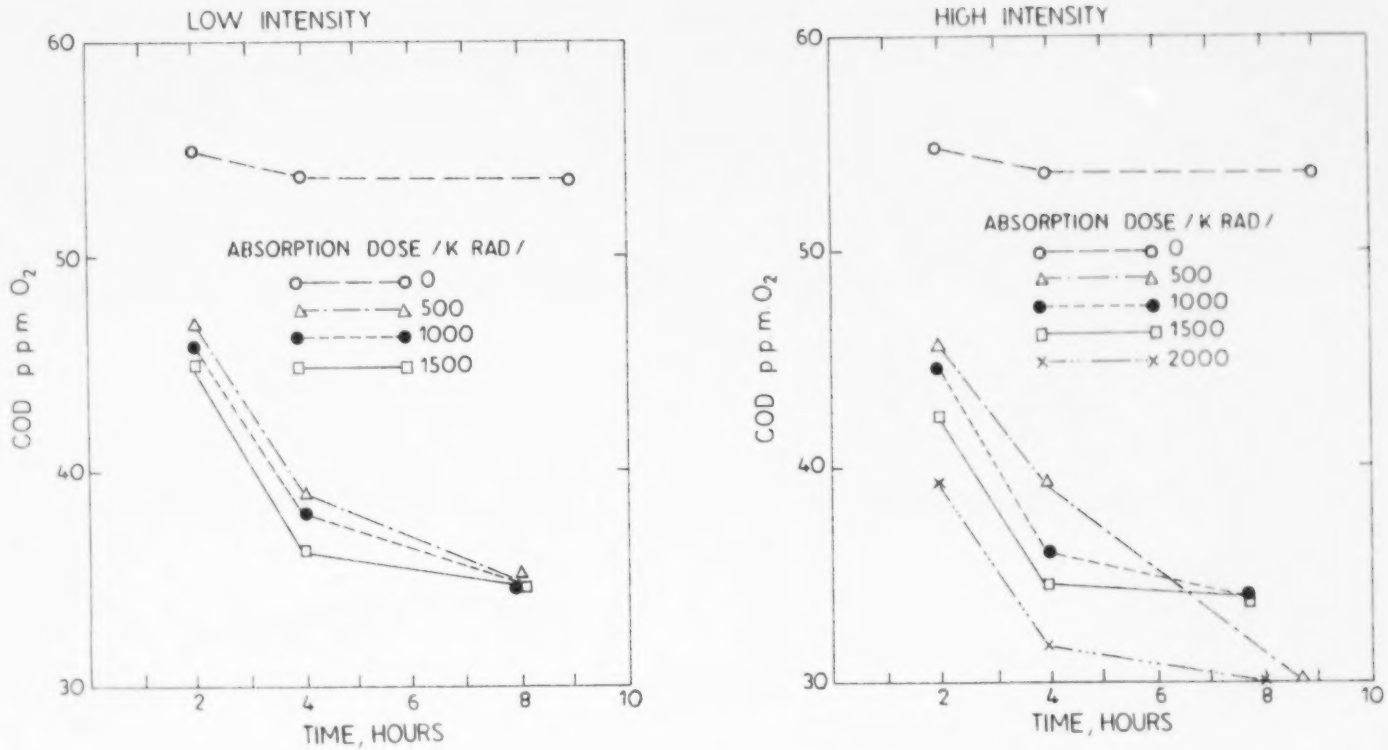


Figure 32. Radiation application effect on COD. Konin mine water. Sample II, pH-8.11

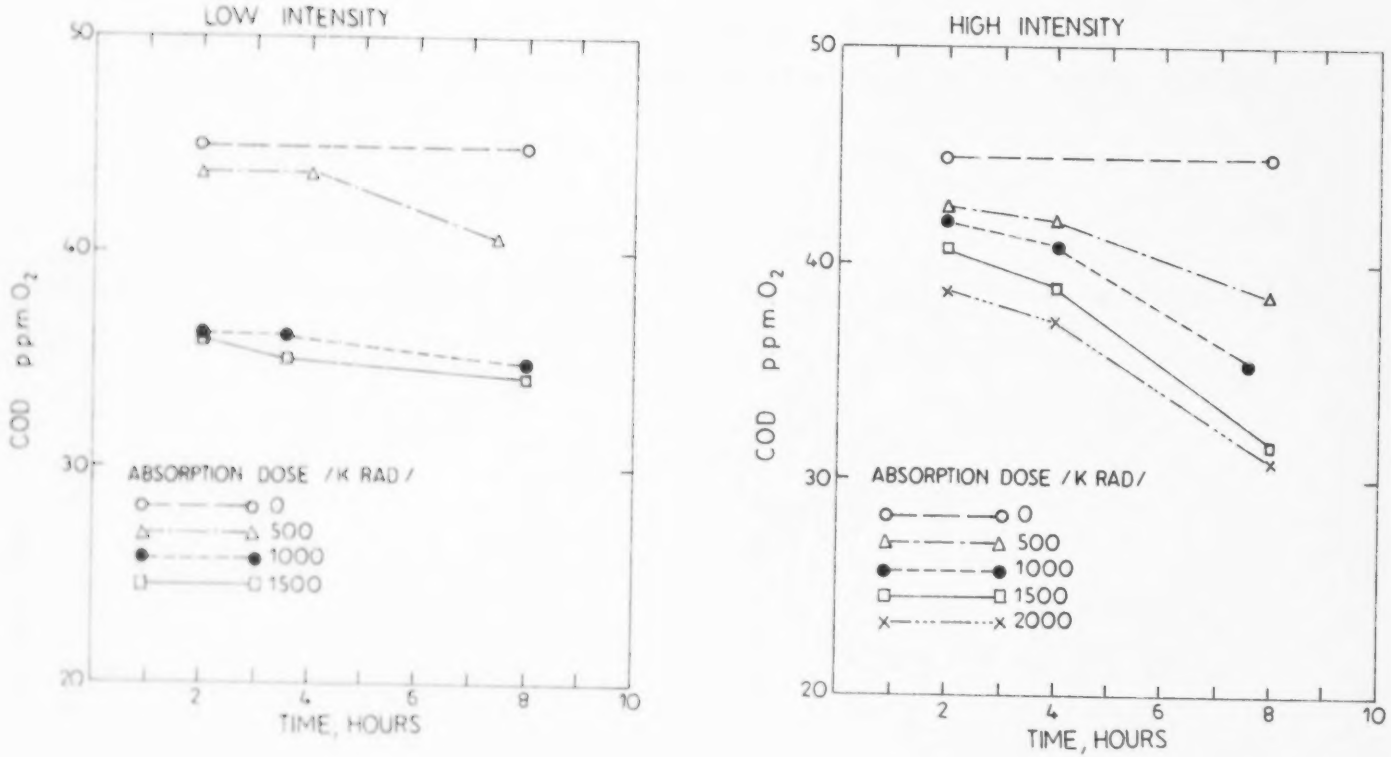


Figure 33. Radiation application effect on COD. Turów mine water. Sample II, pH- 7.78

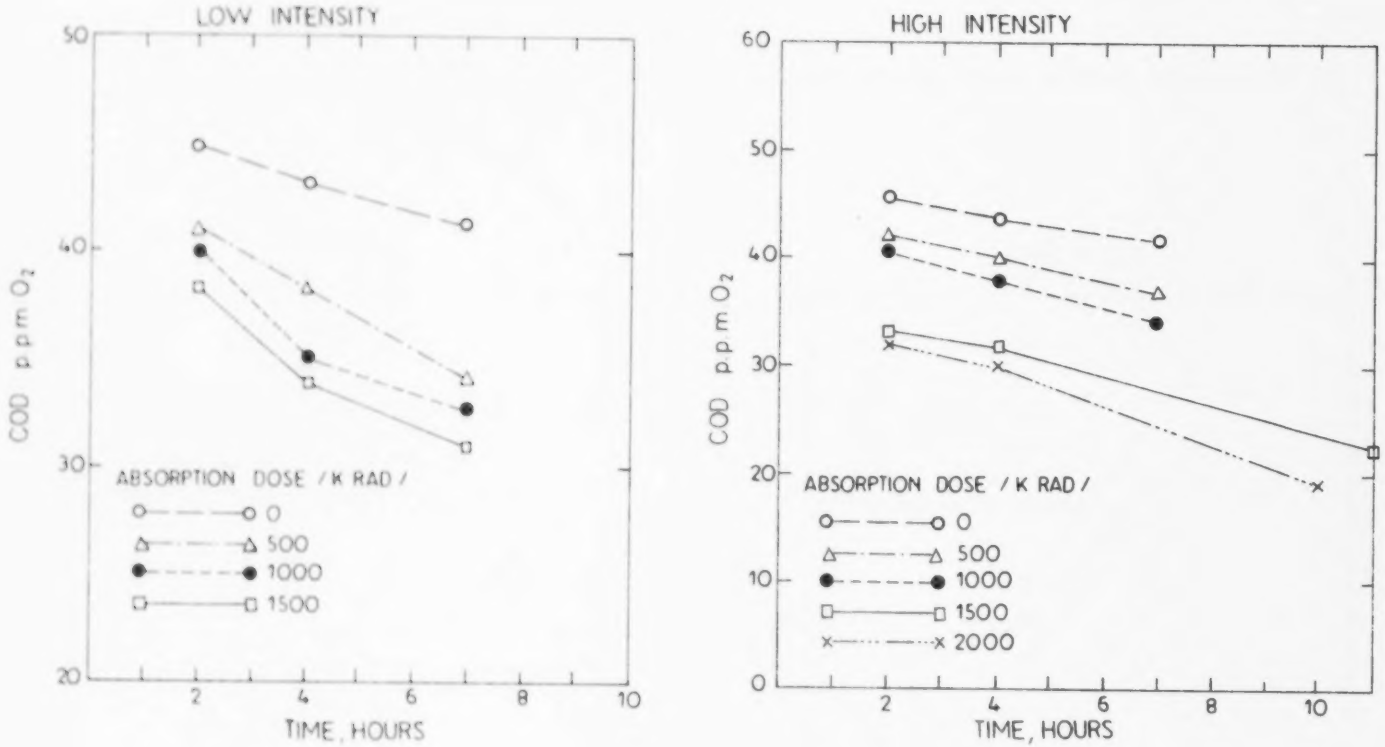


Figure 34. Radiation application effect on COD. Turów mine water. Sample II, pH-7.94

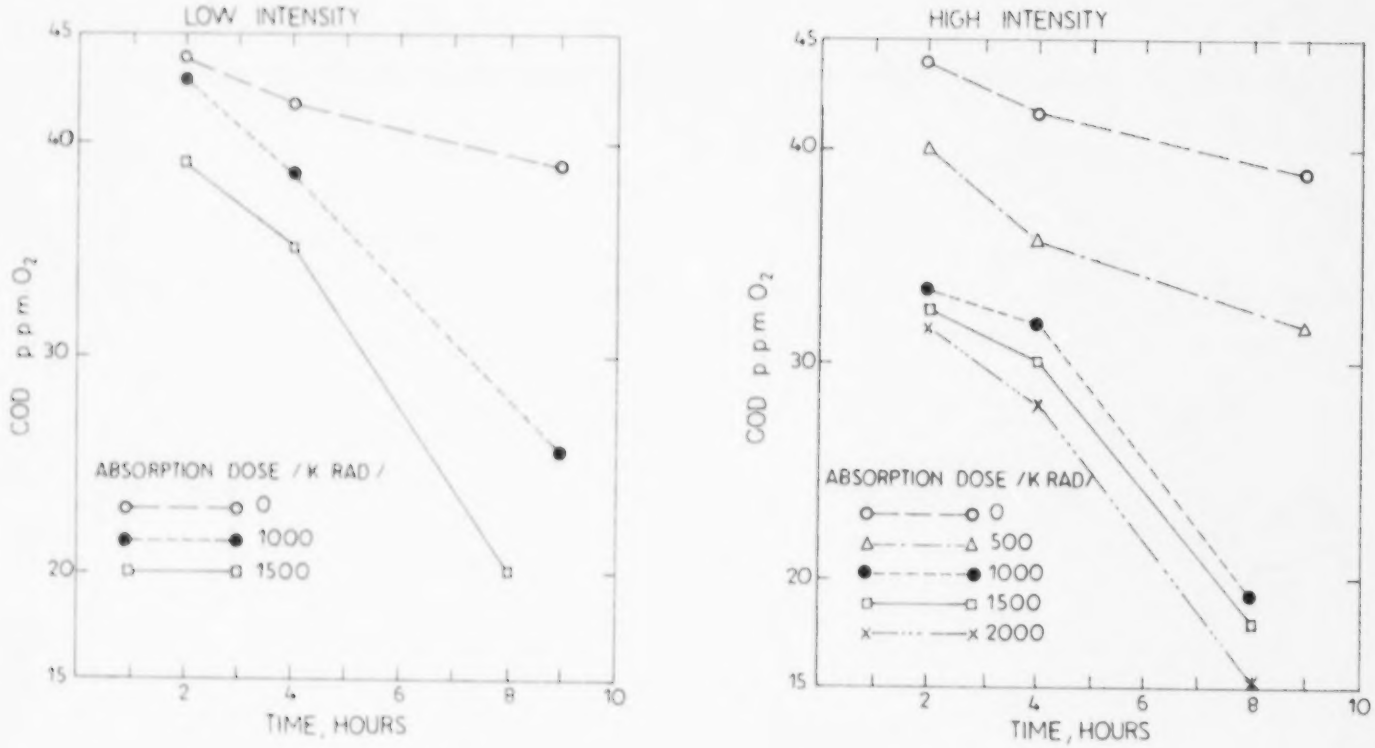


Figure 35. Radiation application effect on COD. Turów mine water. Sample II, pH-8.24

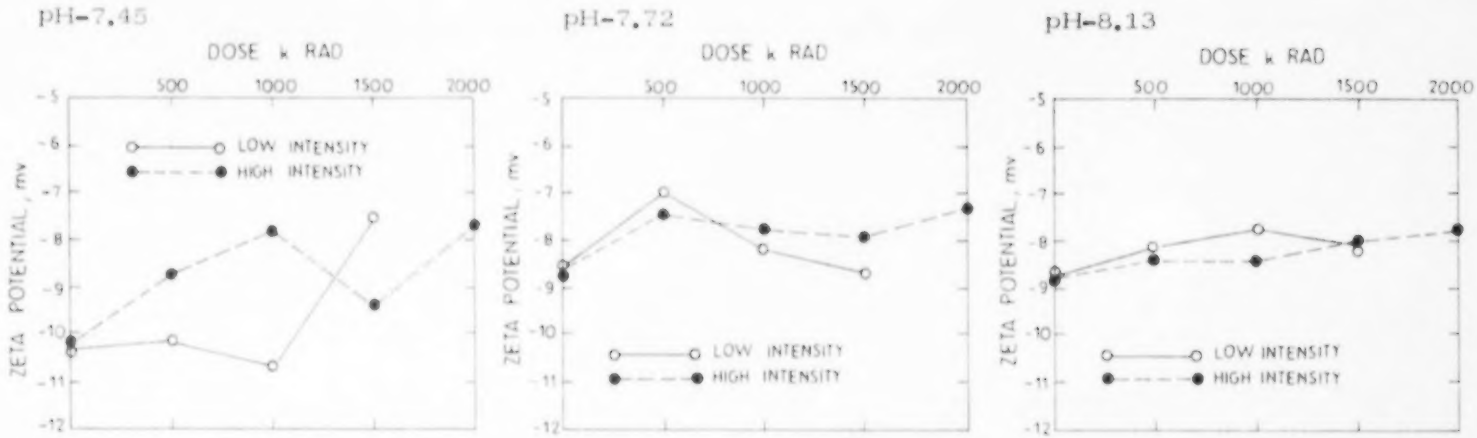


Figure 36. Radiation application effect on zeta potential, Adamów mine water, Sample III.

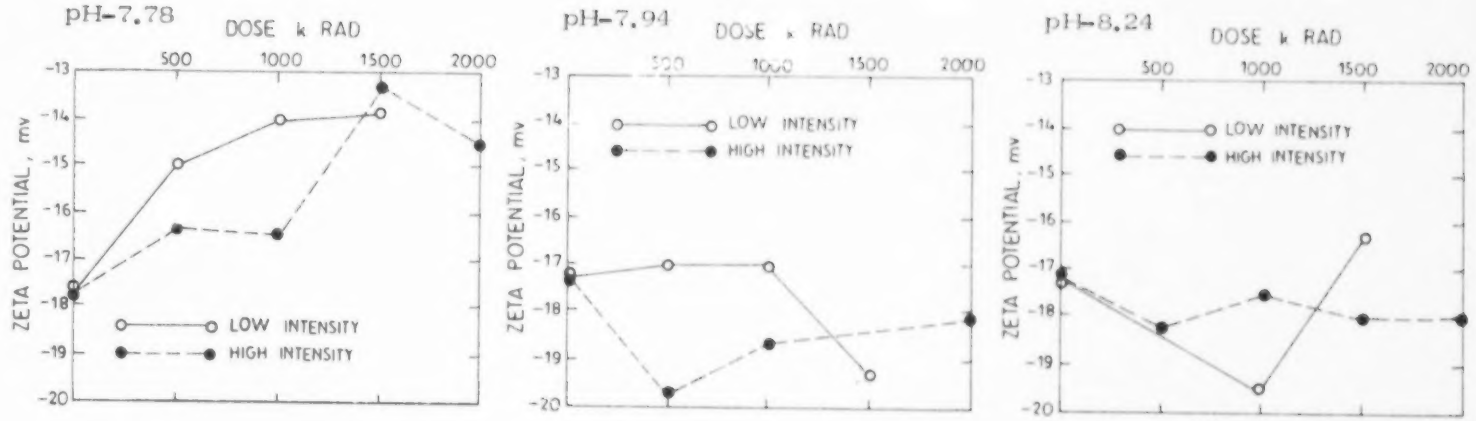


Figure 37. Radiation application effect on zeta potential. Turów mine water. Sample II.

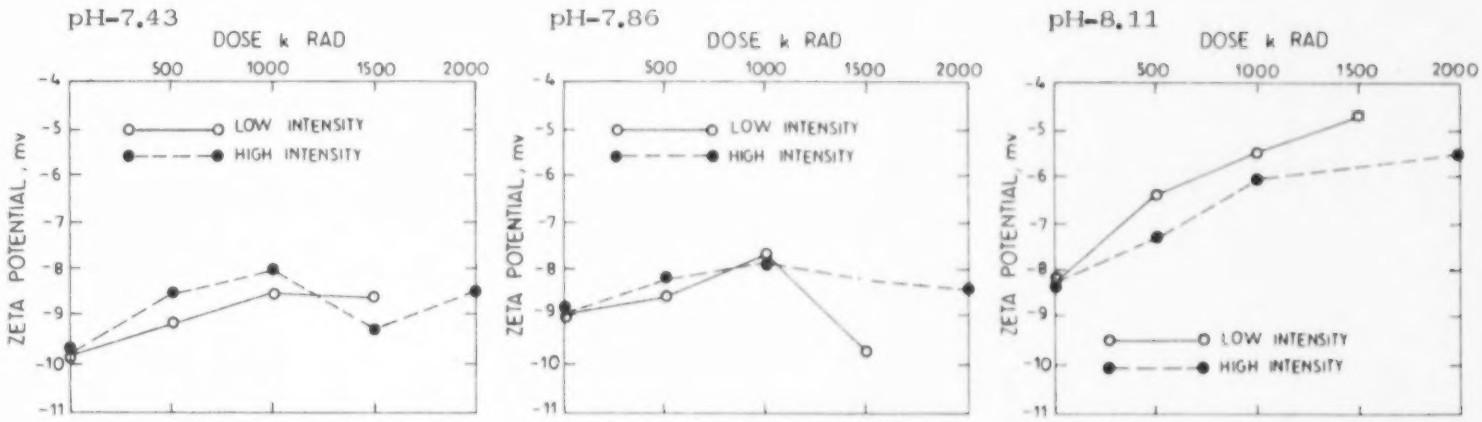


Figure 38. Radiation application effect on zeta potential. Konin mine water. Sample II.

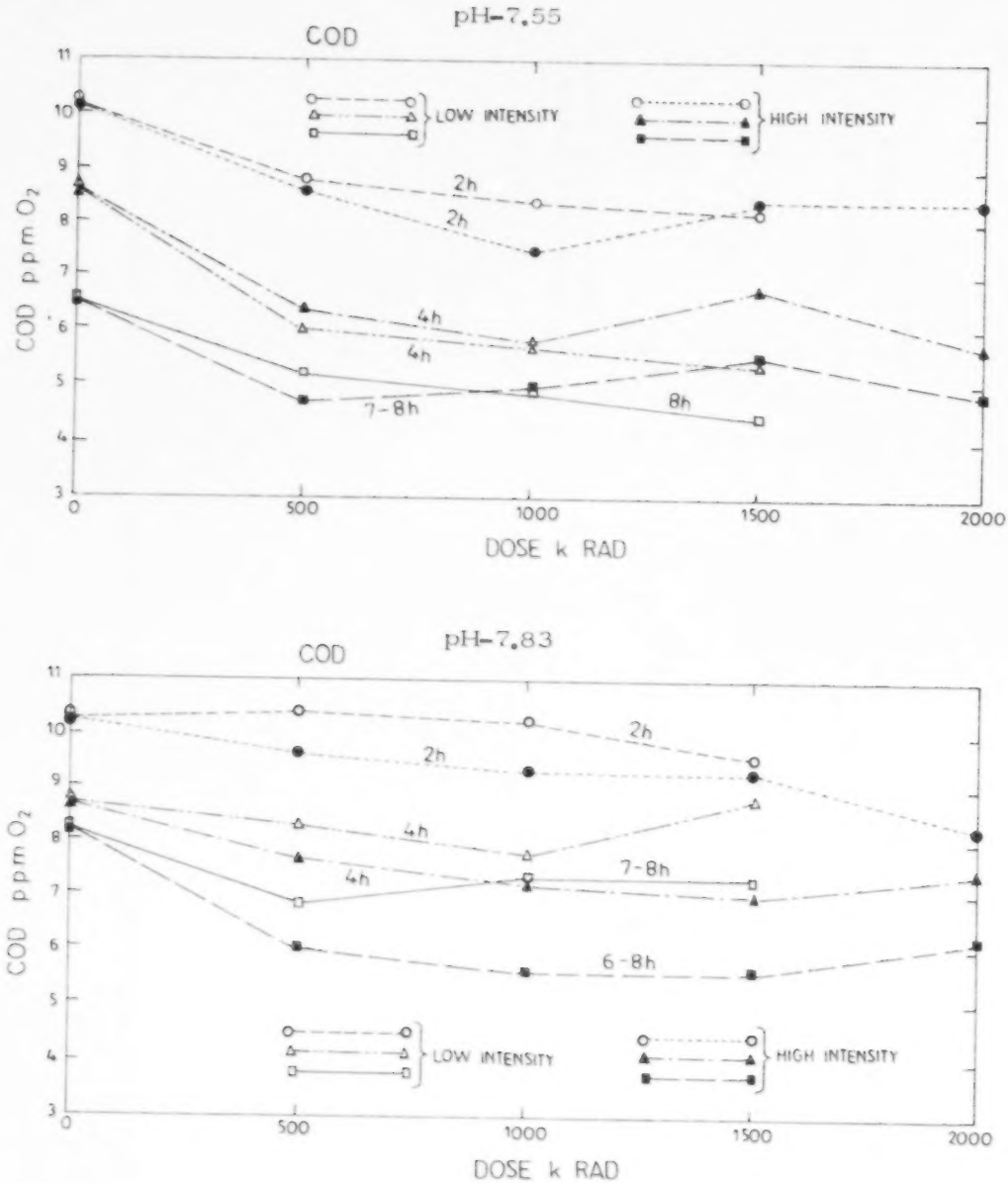
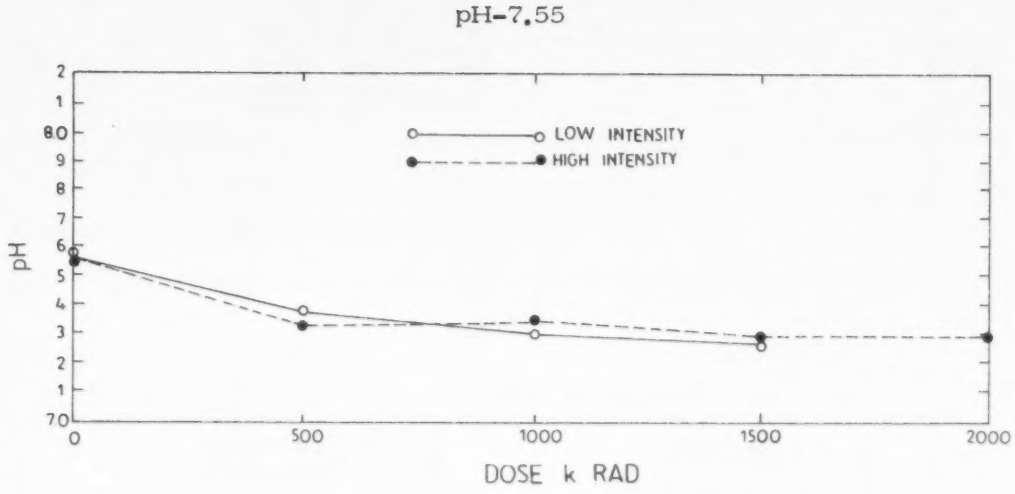


Figure 39. Radiation application effect. Konin mine water. Sample V.



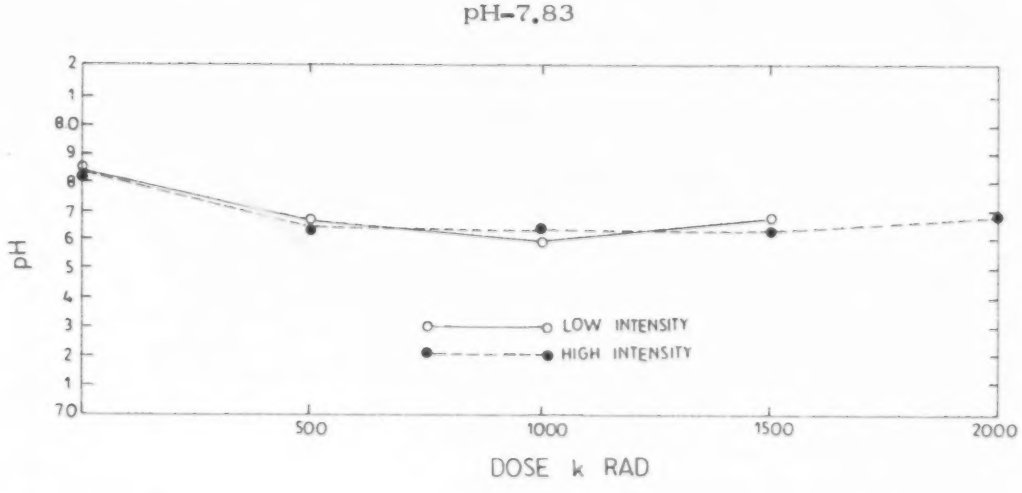


Figure 40. Radiation application effect. Konin mine water. Sample V.

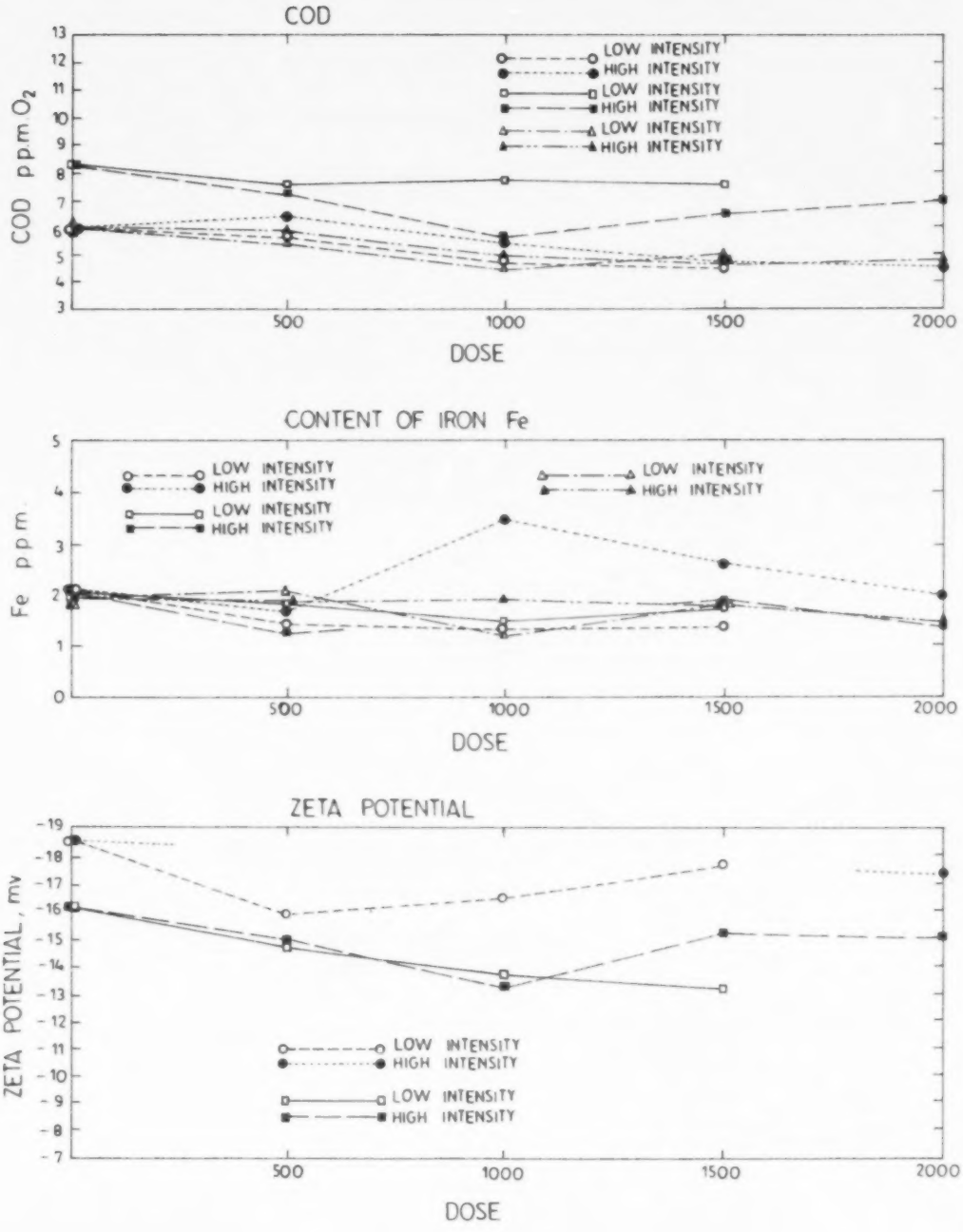


Figure 41. Radiation application effect. Adamów mine water. Sample IV.

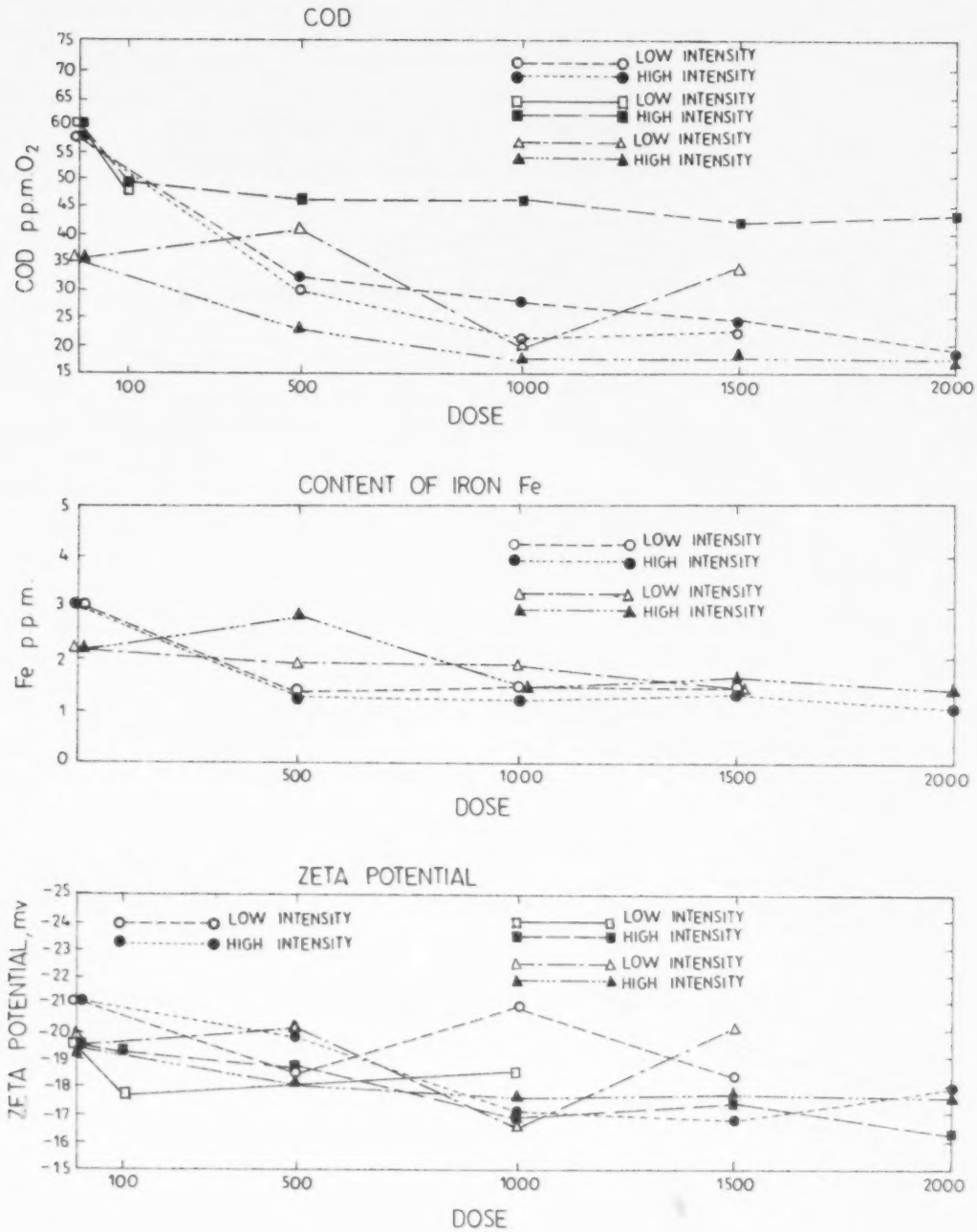


Figure 42. Radiation application effect. Turów mine water. Sample II.

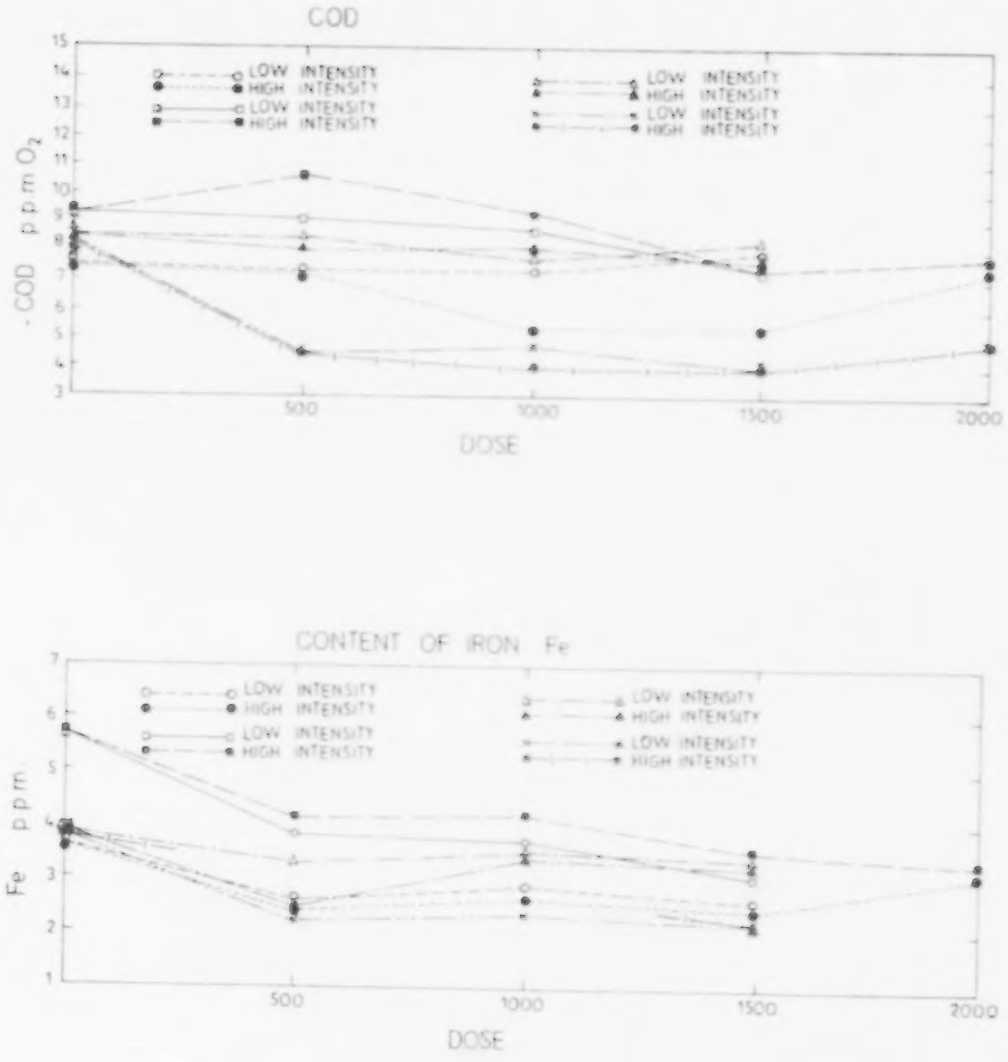


Figure 43. Radiation application effect. Adamów mine water. Sample III.

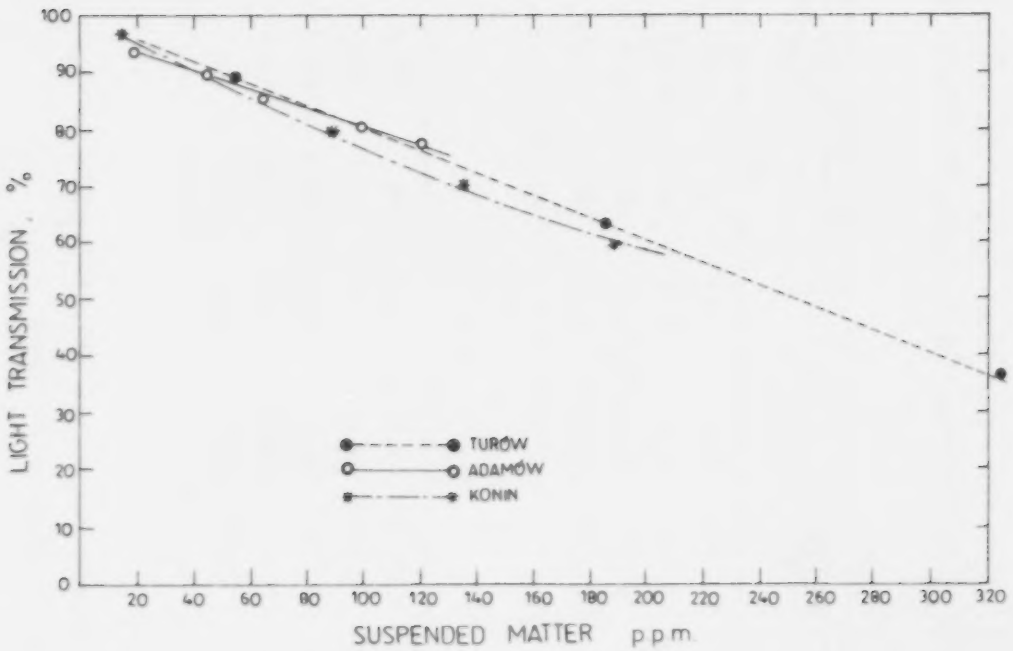


Figure 44. Relation between the suspended matter quantity and the transmittance measured with specord with a wave lenght 400 nm.

TABLE 2. RESULTS OF TEST. ADAMOW-MINE WATER. SAMPLE III pH-7.45

Low intensity

Absorption dose (KRad)	Light transmitance					pH	Potential mv.	Chem. oxygen. d.(p.p.m.)		
	0h	2h	4h	8h	24h			2h	4h	8h
0	11.5	16.0	20.5	35.5/10/	62.5	7.45	-8.7	59.0	45.0	34.5/10/
500	-	30.0	52.5	74.5/9/	93.0	7.28	-8.0	45.5	18.2	0.4/9/
1000	-	35.0	57.0	79.0/9/	91.5/22/	7.17	-7.7	44.5	16.5	8.0/9/
1500	-	36.0	57.5	79.0/9/	91.0/22/	7.15	-8.0	43.5	16.0	7.8/9/

High intensity

0	11.5	16.0	20.5	35.5/19/	62.5	7.45	-8.7	59.0	45.0	34.5/10/
500	-	32.0	53.0	78.0/10/	92.0	7.23	-8.1	46.0	18.0	10.2/10/
1000	-	36.0	59.0	81.0/9/	94.0	7.18	-8.2	43.5	15.7	8.4/9/
1500	-	36.0	60.0	78.0	94.0	7.15	-7.9	42.0	15.2	8.5
2000	-	39.0	66.0	78.5/7/	94.5	7.11	-7.7	40.0	14.0	9.0/7/

Notice: Values given in brackets signify an actual time of sample taking from the moment of finished irradiation process

TABLE 3. RESULTS OF TEST. ADAMOW-MINE WATER. SAMPLE III pH-7.72

Low intensity

Absorption dose (KRad)	Light transmitance 0h	2h	4h	8h	24h	pH	Foten-tial mv.	Chem. oxygen. d. (p.p.m.) 2h	4h	8h
0	11.5	17.0	23.0	51.0	69.5/25/	7.72	-8.45	58.0	43.0	28.5
500	-	33.5	54.0	74.0	92.0	7.40	-6.9	46.0	19.0	11.4
1000	-	34.5	57.5	78.0	89.5/21/	7.30	8.05	45.0	18.4	11.0
1500	-	36.0	60.0	78.0	89.0/20/	7.26	8.50	42.5	16.8	10.0

High intensity

0	11.5	17.0	23.0	51.0	69.5/25/	7.72	-8.45	58.0	43.0	28.5
500	-	37.5	65.0	75.0	92.0/25/	7.40	-7.2	45.0	29.0	11.8
1000	-	40.5	70.0	80.0	92.5	7.29	-7.6	42.0	26.0	11.5
1500	-	42.5	67.5	84.5/11	94.0	7.27	-7.8	41.5	20.0	11.0
2000	-	39.0	57.0	74.5/7/	92.0/23/	7.25	-7.2	40.0	19.2	11.5/7/

TABLE 4. RESULTS OF TEST. ADAMOW-MINE WATER. SAMPLE III pH-8.13

Low intensity

Absorption dose (KRad)	Light transmitance 0h	2h	4h	8h	24h	pH	Potential mv.	Chem oxygen. d.(p.p.m.) 2h	4h	8h
0	11.0	14.0	19.0	31.0/9/	47.5	8.13	-10.2	61.0	46.0	35.0/9/
500	-	25.0	48.5	70.5	81.5	7.51	-10.1	46.5	19.5	10.2
1000	-	32.5	53.5	73.0	86.5/20/	7.50	-10.6	45.0	16.6	9.4
1500	-	35.5	60.0	75.0	90.0/20/	7.47	- 7.5	44.5	14.5	9.0

High intensity

0	11.0	14.0	19.0	31.0/9/	47.5	8.13	-10.2	61.0	46.0	35.0/9/
500	-	27.5	47.0	70.5/9/	89.0/25	7.57	- 8.6	45.5	17.5	12.4/9/
1000	-	35.0	61.0	72.0	87.5	7.50	- 7.8	44.0	17.4	9.6
1500	-	34.0	59.0	80.0/9/	90.0	7.39	9.2	45.5	17.0	9.5/9/
2000	-	42.5	61.0	81.0	93.0	7.40	7.5	45.0	17.0	8.7

TABLE 5. RESULTS OF TEST. KONIN MINE WATER. SAMPLE II pH-7.43

Low intensity

Absorption dose (KRad)	Light transmitance					pH	Potential mV.	Chem. oxygen. d. (p.p.m.)		
	0h	2h	4h	8h	24h			2h	4h	8h
0	77.0	78.0	79.0	81.5	84.0	7.43	-9.7	5.6	5.6	5.5
500	-	80.5	84.0	92.5	95.5	7.19	-9.0	5.2	5.0	4.8
1000	-	83.0	89.0	93.0	99.0/20/	7.10	-8.4	4.9	4.5	4.0
1500	-	83.5	88.5	93.5	99.0/19/	7.10	-8.6	4.8	4.3	3.7

High intensity

0	77.0	78.0	79.0	81.5	84.0	7.43	-9.7	5.6	5.6	5.5
500	-	81.5	86.0	93.0	95.5	7.19	-8.5	5.3	5.2	5.1
1000	-	83.0	89.0	96.0	99.0	7.19	-8.0	5.2	5.0	4.5
1500	-	83.0	90.0	93.0	98.0/20/	7.11	-9.2	4.6	3.6	3.0
2000	-	84.0	89.5	94.0	99.0/19/	7.02	-8.4	4.5	3.4	3.0

TABLE 6. RESULTS OF TEST. KONIN MINE WATER. SAMPLE II pH-7.86

Low intensity

Absorption dose (KRad)	Light transmitance					pH	Potential mv.	Chem. oxygen. d.(p.p.m.)		
	0h	2h	4h	8h	24h			2h	4h	8h
0	72.5	76.0	79.5	82.0	87.5	7.86	-8.9	5.7	5.6	5.6
500	-	78.5	84.5	86.0	95.0	7.42	-8.4	5.6	5.4	5.1
1000	-	79.0	86.0	88.0	95.0/18/	7.38	-7.6	5.4	5.1	4.7/9/
1500	-	80.0	88.5	90.5	99.0/18/	7.37	-9.6	5.2	5.1	4.5/1/

High intensity

0	72.5	76.0	79.5	82.0	87.5	7.86	-8.9	5.7	5.6	5.6
500	-	79.5	87.0	88.5/9/	95.0	7.42	-8.1	5.5	5.3	5.1
1000	-	80.5	87.0	90.5	96.0	7.38	-7.7	5.5	5.2	4.9/10/
1500	-	81.0	88.5	91.5	95.5/18/	7.37	-8.1	5.4	5.1	4.8/9/
2000	-	81.5	91.0	94.0	98.0/18/	7.33	-8.3	5.1	5.0	4.6/9/

TABLE 7. RESULTS OF TEST. KONIN MINE WATER. SAMPLE II. pH-8.11

Low intensity

Absorption dose (KRad)	Light transmitance					pH	Potential mv.	Chem.oxygen.d. (p.p.m.)		
	0h	2h	4h	8h	24h			2h	4h	8h
0	73.0	74.0	75.0	79.0	84.0	8.11	-8.2	5.5	5.4	5.4/9/
500	-	79.0	86.0	89.0	93.0	7.70	-6.3	4.7	3.9	3.5
1000	-	78.5	84.0	88.0/6/	95.5/20/	7.67	-5.4	4.6	3.8	3.5
2000	-	78.0	82.0	84.0/6/	93.0/20/	7.63	-4.7	4.5	3.6	3.5

High intensity

0	73.0	74.0	75.0	79.0	84.0	8.11	-8.2	5.5	5.4	5.4/9/
500	-	75.0	78.0	86.0	96.0	7.67	-7.2	4.6	4.0	3.0/9/
1000	-	88.0	89.0	90.0	98.0	7.56	-6.0	4.5	3.6	3.3
1500	-	86.0	89.0	91.0	97.5	7.64	-5.7	4.3	3.4	3.3
2000	-	87.0	89.5	93.0/9/	98.5/23/	7.59	-5.4	4.0	3.1	3.0

TABLE 8. RESULTS OF TEST. TUROW MINE WATER. SAMPLE II. pH-7.78

Low intensity

Absorption dose (KRad)	Light transmitance 0h	2h	4h	8h	24h	pH	Potential mv.	Chem.oxygen.d.(p.p.m.) 2h	4h	8h
0	7.0	7.0	7.0	8.0	11.0	7.78	-17.8	45.0	45.0	45.0
500	-	7.0	5.5	13.0	35.0	7.07	-15.0	44.0	44.0	42.0/6/
1000	-	7.0	7.5	10.5	25.5/20/	7.00	-14.1	36.0/1/	36.0/3/	34.5
1500	-	7.0	7.5	12.5	26.5/20/	6.94	-13.9	36.0/1/	35.0/3/	34.0

High intensity

0	7.0	7.0	7.0	8.0	11.0	7.78	-17.8	45.0	45.0	45.0
500	-	7.0	7.5	13.0	37.5	7.03	-16.3	43.0	42.0	38.0
1000	-	7.5	8.5	16.5	48.5	7.04	-16.5	42.5	41.0	36.0/7/
1500	-	8.0	9.0	15.5	44.0	6.98	-13.2	41.0	39.0	32.0
2000	-	8.0	9.5	17.0	50.0/23/	6.94	-14.0	39.0	37.0	31.5

TABLE 9. RESULTS OF TEST. TURÓW MINE WATER. SAMPLE II. pH-7.94

Low intensity

Absorption dose (KRad)	Light transmitance					pH	Potential mv.	Chem.oxygen.d. (p.p.m.)		
	0h	2h	4h	8h	24h			2h	4h	8h
0	6.0	6.0	7.0	8.0	21.0	7.94	-13.3	45.0	43.0	41.0/7/
500	-	8.0	10.5	18.0/10/	28.0	7.36	-17.0	41.0	38.0	34.0/7/
1000	-	11.0	14.0	18.0/7/	32.0/20/	7.23	-17.0	40.0	35.0	33.0/7/
1500	-	12.5	19.0	30.5/7/	46.0	7.22	-19.3	38.0	34.0	31.0/7/

High intensity

0	6.0	6.0	7.0	8.0	21.0	7.94	-13.3	45.0	43.0	41.0/7/
500	-	10.0	13.5	21.0/9/	32.5	7.29	-19.8	42.0	40.0	36.0/7/
1000	-	10.5	14.5	21.5/9/	34.0	7.24	-18.7	-	39.0/3/	35.0/6/
1500	-	14.0	23.0	38.0/11/	55.5	7.20	-18.4	34.0	32.0	22.5/11/
2000	-	19.5	29.5	42.0/10/	66.0/23/	7.14	-18.1	33.0	30.0	19.6/10/

TABLE 10. RESULTS OF TEST. TUROW MINE WATER. SAMPLE II. pH-8.24

Low intensity

Absorption dose (KRad)	Light transmitance					pH	Potential mv.	Chem.oxygen. d.(p.p.m.)		
	0h	2h	4h	8h	24h			2h	4h	8h
0	7.0	7.0	7.0	7.0	11.5	8.24	-13.1	44.0	42.0	39.0/9/
500										
1000	-	7.0	7.5	16.5/9/	40.5/18/	7.54	-15.4	43.0	38.0	25.0/9/
1500	-	7.5	8.0	20.0/9/	43.5/18/	7.43	-12.3	39.0	35.0	20.0

High intensity

0	7.0	7.0	7.0	7.0	11.5	8.24	-13.1	44.0	42.0	39.0/9/
500	-	7.0	8.0	15.0/9/	49.0	7.50	-14.1	40.0	36.0	32.0/9/
1000	-	7.0	8.0	30.5	63.5	7.45	-13.4	34.0	32.0	19.0
1500	-	8.0	10.5	35.0	69.5/22/	7.37	-13.9	33.5	30.0	18.0
2000	-	12.5	21.0	43.0	67.5/21/	7.35	-13.9	33.0	27.5	14.4

TABLE 11. RESULTS OF TEST. TUROW MINE WATER. SAMPLE II pH-7.4

Low intensity

Absorption dose (K Rad)	Light transmitance 0h	1h	2h	4h	24h	Potential (mV)	C.O.D. (p.p.m.)	Content of iron Fe (p.p.m.)
0	6.0	6.0	7.0	7.5	49.0	-19.6	60.5	-
100	-	7.0	7.0	7.5	60.0	-17.7	48.0	-
1000	-	8.0	22.0	33.5	88.0	-18.6	-	-

High intensity

0	6.0	6.0	7.0	7.5	49.0	-19.6	60.5	-
100	-	7.0	7.0	7.5	60.0	-19.2	49.5	-
500	-	7.5	8.5	20.5	84.0	-18.7	47.0	-
1000	-	9.5	28.0	40.0	88.5	-17.0	47.0	-
1500	-	29.5	46.0	61.5	91.5	-17.5	43.0	-
2000	-	49.0	63.0	76.0	96.0	-16.3	43.5	-

TABLE 12. RESULTS OF TEST. TUROW MINE WATER. SAMPLE II pH-5.5

Low intensity

Absorption dose (k Rad)	Light transmitance 0h	1h	2h	4h	24h	Potential (mV)	C.O.D. (p.p.m.)	Content of iron Fe (p.p.m.)
0	0.5	0.5	3.0	16.0	91.0	-21.2	58.0	3.06
500	-	1.0	5.0	18.5	87.5	-18.4	30.0	1.32
1000	-	3.5	9.0	25.0	93.0	-20.8	22.0	1.47
1500	-	3.0	10.0	27.0	91.5	-18.4	23.0	1.47

High intensity

0	0.5	0.5	3.0	16.0	91.0	-21.2	58.0	3.06
500	-	0.5	2.5	11.5	88.0	-19.8	32.0	1.32
1000	-	1.0	4.0	17.0	91.0	-17.1	28.5	1.32
1500	-	3.5	4.5	21.0	92.0	-16.9	24.5	1.40
2000	-	7.0	20.0	35.5	100.0	-18.0	17.5	1.03

TABLE 13. RESULTS OF TEST. TUROW MINE WATER. SAMPLE II pH-9.5

Low intensity

Absorption dose (K Rad)	Light transmitance 0h	1h	2h	4h	24h	Potential (mV)	C.O.D. (p.p.m.)	Content of iron Fe (p.p.m.)
0	2.0	2.5	8.5	23.0	78.0	-19.7	36.0	2.20
500	-	3.0	8.5	24.0	79.0	-20.5	42.0	1.98
1000	-	5.5	13.0	26.0	82.5	-16.9	20.5	1.98
1500	-	2.5	10.0	18.0	77.0	-20.1	34.0	1.47

High intensity

0	2.0	2.5	8.5	23.0	78.0	-19.7	36.0	2.20
500	-	3.5	8.0	18.0	78.5	-18.2	23.5	2.92
1000	-	12.0	16.0	38.0	86.0	-17.6	17.5	1.47
1500	-	18.0	26.0	47.0	79.0	-17.9	17.5	1.52
2000	-	21.0	33.5	45.5	91.0	-17.9	17.5	1.32

TABLE 14. RESULTS OF TEST. ADAMÓW MINE WATER. SAMPLE III pH-7.75

Low intensity

Absorption dose (K Rad)	Light transmitance 0h	1h	2h	4h	24h	C.O.D. (p.p.m.)	Content of iron Fe (p.p.m.)
0	78	81	82	88	100	7.6	3.73
500	-	81	84	91	100	7.4	2.63
1000	-	81	88	99	100	7.4	2.93
1500	-	81	85.5	93	100	8.0	2.63

High intensity

0	78	81	82	88	100	7.6	3.73
500	-	83.5	91	97	100	7.4	2.50
1000	-	83	89.5	99	100	5.3	2.63
1500	-	80.5	82	97	100	5.4	2.50
2000	-	-	85	91	100	7.4	3.07

TABLE 15. RESULTS OF TEST. ADAMÓW MINE WATER. SAMPLE III pH- 6.0

Low intensity

Absorption dose (K Rad)	Light transmitance					C.O.D. (p.p.m.)	Content of iron Fe (p.p.m.)
	0h	1h	2h	4h	24h		
0	68	69	70.5	72	90.5	9.2	5.70
500	-	69	72	77	96.5	9.0	3.80
1000	-	68.5	-	82	90.0	8.8	3.73
1500	-	69	71.5	85.5	98.0	7.2	3.00

High intensity

0	68	69	70.5	72	90.5	9.2	5.70
500	-	69	74	78.5	96	10.6	4.10
1000	-	69	70	86	96	9.2	4.16
1500	-	69.5	72	78	95	7.2	3.65
2000	-	70	73	82	95	7.8	3.22

TABLE 16. RESULTS OF TEST. ADAMOW MINE WATER. SAMPLE III pH-7.0

Low intensity

Absorption dose (K Rad)	Light transmitance 0h	1h	2h	4h	24h	C.O.D. (p.p.m.)	Content of iron Fe (p.p.m.)
0	-	68	74	75	100(25h)	8.4	3.87
500	-	67	76	80	100	8.4	3.37
1000	-	69	-	78.5	100	7.8	3.66
1500	-	71	-	79.5	100	8.2	3.58

High intensity

0	-	68	74	75	100(25h)	8.4	3.87
500	-	69.5	79	85	100	8.0	2.50
1000	-	69	73.5	84	100	8.2	3.48
1500	-	69	71.5	81	100	7.8	3.31
2000	-	69.5	71.5	85	100(23h)	-	-

TABLE 17. RESULTS OF TEST. ADAMOW MINE WATER. SAMPLE III pH-9.0

Low intensity

Absorption dose (K Rad)	Light transmitance					C.O.D. (p.p.m.)	Content of iron Fe (p.p.m.)
	0h	1h	2h	4h	24h		
0	67.5	70	74.5	79	90	8.0	3.80
500	-	70	78	90	97	4.5	2.27
1000	-	68.5	79	88	97	4.7	2.50
1500	-	71	82.5	91.5	97	4.0	2.27

High intensity

0	67.5	70	74.5	79	90	8.0	3.80
500	-	80	81.5	90	98	4.5	-
1000	-	79	83	89	97	4.0	-
1500	-	72	82.5	98.5	97	4.0	2.27
2000	-	68	80	89.5	98	4.8	-

TABLE 18. RESULTS OF TEST. ADAMOW MINE WATER. SAMPLE IV pH-7.85

Low intensity

Absorption dose (K Rad)	Light transmitance (400 nm) 0h	1h	2h	4h	24h	Potential's (mV)	C.C.D. (p.p.m.)	Content of iron Fe (p.p.m.)
0	77	78	78	80	97	-16.2	8.2	2.01
500	-	82	83.5	84.5	98	-14.8	7.6	1.61
1000	-	80	84	86	98.5	-13.8	7.8	1.46
1500	-	80	82	84.5	98	-13.1	7.6	1.69

High intensity

0	77	78	78	80	97	-16.2	8.2	2.01
500	-	80	84	88.5	98	-15.0	7.4	1.40
1000	-	80.5	81	85.5	98	-13.2	5.7	-
1500	-	80.5	82	86	97	-15.1	6.5	1.84
2000	-	81	86	89.5	99.5	-15.0	7.0	1.46

TABLE 19. RESULTS OF TEST. ADAMOW MINE WATER. SAMPLE IV pH-7.45

Low intensity

Absorption dose (K Rad)	Light transmitance (400 nm.)					Potential's (mV)	C.C.D. (p.p.m.)	Content of iron Fe (p.p.m.)
	0h	1h	2h	4h	24h			
0	78	83.0	86	86	94.5	-18.7	6.0	2.09
500	-	87.5	88	88	98	-15.9	5.7	1.54
1000	-	87.5	88	88.5	98.5	-16.4	4.8	1.35
1500	-	87.5	88	89	97.5	-17.7	4.5	1.40

High intensity

0	78	83	86	86	94.5	-18.7	6.0	2.09
500	-	89	90	90	96	-	6.3	1.56
1000	-	87	89.5	88.5	98	-	5.6	3.54
1500	-	87.5	88	89	97	-	4.8	2.75
2000	-	87.5	88	88.5	98	-17.4	4.6	2.00

TABLE 20. RESULTS OF TEST. ADAMOW MINE WATER. SAMPLE IV pH-8.1

Low intensity

Absorption dose (K Rad)	Light transmitance (400 nm) 0h	1h	2h	4h	24h	Potential's (mV)	C.C.D. (p.p.m.)	Content of iron Fe (p.p.m.)
0	81	82	84	85	95		6.0	2.00
500	-	84.5	86	86.5	94.5	(8-10)	5.5	2.07
1000	-	84	85	87	96.5		4.7	1.34
1500	-	83.5	84.5	87	97.5		5.0	1.80

High intensity

0	81	82	84	85	93		6.0	2.00
500	-	84	86.5	87.5	95.5		5.9	1.75
1000	-	84	85	87	96.5	(8-10)	4.8	1.97
1500	-	85	86	87	96.5		4.7	1.85
2000	-	84.5	85.5	87	95		4.8	1.48

TABLE 21. RESULTS OF TEST. KONIN MINE WATER. SAMPLE V. pH-7.55

Low intensity

Absorption dose (K Rad)	Light transmitance (400 nm) 0h	1h	2h	4h	8h	24h	Dose pH (p.p.m.)	C.C.D. (p.p.m.) 2h	4h	8h
0	54	56	61	63	69	86.5	7.55	10.2	8.6	6.6
500	-	57	62	76	84.5(7h)	94(21h)	7.38	8.8	6.0	5.2
1000	-	57.5	70	79.5	87(9h)	96(19h)	7.30	8.4	5.7	4.9
1500	-	58	75.5(3h)	-	86.7	96(18h)	7.26	8.2	5.4	4.5

High intensity

0	54	-	61	66	69	88	7.55	10.2	8.6	6.6
500	-	-	74	81.5	89.5	94(22h)	7.32	8.6	6.4	4.7
1000	-	-	61	75	89	96(23h)	7.33	7.5	5.8	5.0
1500	-	-	61	79	84.5(12h)	95.5(22h)	7.29	8.4	6.8	5.5(7h)
2000	-	-	67	84.5	88(7h)	96(21h)	7.29	8.4	5.7	4.9(7h)

TABLE 22. RESULTS OF TEST. KONIN MINE WATER. SAMPLE V. pH-7.83

Low intensity

Absorption dose (K Rad)	Light transmitance (400 nm) 0h	1h	2h	4h	8h	24h	Dose pH (p.p.m.)	C.O.D. (p.p.m.) 2h	4h	8h
0	54.5	57.0	62.0	68.0	80.0	91.5	7.83	10.2	8.8	8.2
500	-	-	69.5	75.0	79.5	95.0	7.68	10.4	8.3	6.9
1000	-	-	65.5	77.5	86(6h)	97(20h)	7.60	10.2	7.8	7.2
1500	-	-	64.0	77.5	83(6h)	96.5(20h)	7.68	9.6	8.8	7.2(7h)

High intensity

0	54.5	56.0	62.0	68.0	80.0	86.5(21h)	7.83	10.2	8.8	8.2
500	-	59.5	69.5	74.5	84.0	93.0	7.67	9.6	7.7	6.0
1000	-	-	72.5	79.0	88(7h)	95.0	7.63	9.4	7.1	5.6(7h)
1500	-	-	73.0	82.0	90(7h)	95(23h)	7.63	9.4	7.0	5.6(7h)
2000	-	58.5	72.0	85.0	91.0	97.5(21h)	7.68	8.2	7.4	6.2(6h)